

Final Draft

Public Health Assessment

Lower Duwamish Waterway
Seattle, King County, Washington
CERCLIS NO. WA0002329803

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Prepared by

**Washington State Department of Health
Under Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry**



Foreword

The Washington State Department of Health (DOH) has prepared this public health assessment in cooperation with the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR, part of the US Department of Health and Human Services, is the principal federal public health agency responsible for health issues related to hazardous waste. This health assessment was prepared in accordance with methodologies and guidelines developed by ATSDR.

The purpose of this health assessment is to identify and prevent harmful human health effects resulting from exposure to hazardous substances in the environment. Public health assessments evaluate sampling data collected from hazardous waste sites; determine whether exposures have occurred in the past, are presently occurring, or could occur in the future; and recommend actions to be implemented to protect public health. Where data is limited or unavailable, DOH identifies critical data gaps that need to be filled so that public health decisions can be made.

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Acronyms and Abbreviations

ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CREG	Cancer Risk Evaluation Guide
COC	Contaminant of Concern
CSO	Combined Sewer Overflow
DOH	Washington State Department of Health
DRCC	Duwamish River Cleanup Coalition
Ecology	Washington State Department of Ecology
ECOSS	Environmental Coalition of South Seattle
EMEG	Environmental Media Evaluation Guide
EPA	U.S. Environmental Protection Agency
ICD	International Classification of Disease
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LOAEL	Lowest Observed Adverse Effect Level
MRL	Minimum Risk Level
MTCA	Model Toxics Control Act
NOAEL	No Observed Adverse Effect Level
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
PAEP	Pacific Asian Empowerment Program
PCB	Polychlorinated Biphenyl
RfD	Reference Dose
RMEG	Reference Dose Media Evaluation Guide
PH-SKC	Public Health - Seattle & King County
WDFW	Washington State Department of Fish and Wildlife

Units of Measure

g	gram
g/day	grams per day
kg	kilogram
mg	milligram
mg/l	milligrams per liter = parts per million
mg/kg	milligrams per kilogram = parts per million
mg/kg/day	milligrams per kilogram per day
ppb	parts per billion
ppm	parts per million
μg	microgram
$\mu\text{g/l}$	micrograms per liter = parts per billion
$\mu\text{g/kg}$	micrograms per kilogram = parts per billion

Glossary

Acute	Occurring over a short time [compare with <i>chronic</i>]
Agency for Toxic Substances and Disease Registry (ATSDR)	The principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of the US Department of Health and Human Services.
Anadromous Fish	Fish that ascend rivers from the sea at certain seasons for breeding, such as salmon.
Benthic Fish	Fish that live and eat near the bottom of a water body.
Cancer Risk Evaluation Guide (CREG)	The concentration of a chemical in air, soil, or water that is expected to cause no more than one excess cancer in a million persons exposed over a lifetime. The CREG is a <i>comparison value</i> used to select contaminants of potential health concern and is based on the <i>cancer slope factor</i> (CSF).
Cancer Slope Factor	A number assigned to a cancer-causing chemical that is used to estimate its ability to cause cancer in humans.
Carcinogen	A substance that causes cancer.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as Superfund. This law created a tax on the chemical and petroleum industries and provided broad Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment.
Chronic	Occurring over long time. A chronic exposure is one that lasts for a year or longer.

Comparison value	Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their comparison values might be selected for further evaluation in the public health assessment process.
Congener	A single, unique, well-defined chemical compound in the PCB, dioxin, or furan category. The name of the congener specifies the total number and position of chlorine atoms.
Contaminant	A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An “exposure dose” is how much of a substance is encountered in the environment. An “absorbed dose” is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
Environmental Media Evaluation Guide (EMEG)	A concentration in air, soil, or water below which adverse non-cancer health effects are not expected to occur. The EMEG is a <i>comparison value</i> used to select contaminants of potential health concern and is based on ATSDR’s <i>minimal risk level</i> (MRL).
Epidemiology	The study of the distribution and determinants of disease or health status in a population; the study of the occurrence and causes of health effects in humans.

Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
Groundwater	Water beneath the earth's surface in the spaces between soil particles and between rock surfaces.
Hazardous substance	Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.
Indeterminate public health hazard	The category used in ATSDR's public health assessment documents when a professional judgment about the level of health hazard cannot be made because information critical to such a decision is lacking.
Ingestion rate	The amount of an environmental medium that could be ingested typically on a daily basis. Units for IR are usually liter/day for water, and mg/day for soil.
Inorganic	Compounds composed of mineral materials, including elemental salts and metals such as iron, aluminum, mercury, and zinc.
Lowest Observed Adverse Effect Level (LOAEL)	The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
Maximum Contaminant Level (MCL)	A drinking water regulation established by the federal Safe Drinking Water Act. It is the maximum permissible concentration of a contaminant in water that is delivered to the free flowing outlet of the ultimate user of a public water system. MCLs are enforceable standards.

Media	Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.
Minimal Risk Level (MRL)	An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). MRLs should not be used as predictors of harmful (adverse) health effects.
Model Toxics Control Act (MTCA)	The hazardous waste cleanup law for Washington State.
No apparent public health hazard	A category used in ATSDR's public health assessment documents for sites where human exposure to contaminated media might be occurring, might have occurred in the past, or might occur in the future, but where the exposure is not expected to cause any harmful health effects.
No Observed Adverse Effect Level (NOAEL)	The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
No public health hazard	A category used in ATSDR's public health assessment documents for sites where people have never and will never come into contact with harmful amounts of site-related substances.
Oral Reference Dose (RfD)	An amount of chemical ingested into the body (i.e., dose) below which health effects are not expected. RfDs are published by EPA.
Organic	Compounds composed of carbon, including materials such as solvents, oils, and pesticides that are not easily dissolved in water.

Parts per billion (ppb)/Parts per million (ppm)	Units commonly used to express low concentrations of contaminants. For example, 1 ounce of trichloroethylene (TCE) in 1 million ounces of water is 1 ppm. 1 ounce of TCE in 1 billion ounces of water is 1 ppb. If one drop of TCE is mixed in a competition-size swimming pool, the water will contain about 1 ppb of TCE.
Pelagic Fish	Fish that live and eat near the surface of a water body.
Plume	A volume of a substance that moves from its source to places farther away from the source. Plumes can be described by the volume of air or water they occupy and the direction they move. For example, a plume can be a column of smoke from a chimney or a substance moving with groundwater.
Reference Dose Media Evaluation Guide (RMEG)	A concentration in air, soil, or water below which adverse non-cancer health effects are not expected to occur. The EMEG is a <i>comparison value</i> used to select contaminants of potential health concern and is based on EPA's oral reference dose (RfD).
Remedial investigation	The CERCLA process of determining the type and extent of hazardous material contamination at a site.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].
U.S. Environmental Protection Agency (EPA)	Established in 1970 to bring together parts of various government agencies involved with the control of pollution.
Volatile organic compound (VOC)	Organic compounds that evaporate readily into the air. VOCs include substances such as benzene, toluene, methylene chloride, and methyl chloroform.

Summary

The Lower Duwamish Waterway (LDW) study area is located in King County, Washington, and runs through three jurisdictions: Seattle, King County, and Tukwila. The LDW is a section of the Duwamish River that extends approximately 6 miles from the southern tip of Harbor Island south to Turning Basin #3. On September 13, 2001, the site was listed on the National Priorities List (NPL) by the US Environmental Protection Agency (EPA).

The site is encompassed by industrial and commercial operations, past and present, that include cargo handling and storage, marine construction, boat manufacturing, marina operations, paper and metal fabrication, food processing, and airplane parts manufacturing. In addition, there are over 100 storm drains, combined sewer overflows (CSOs), and other miscellaneous outfalls.¹ These activities have resulted in considerable chemical releases into the LDW over the past 100 years. Contaminant sources include spills and leaks from industrial facilities, industrial operations, waste disposal practices, surface water runoff, storm drain discharge, groundwater discharge, erosion of contaminated soils, atmospheric deposition of industrial air emissions, and CSOs.

DOH gathered a number of community health concerns, many of which related to consumption of fish and other activities involving the river. Common concerns expressed during community interviews and outreach activities related to the safety of consuming salmon harvested from the LDW, seafood consumed from local markets, and a lack of information warning against consumption of seafood harvested from the LDW.

The two major pathways of exposure for residents using the LDW are consumption of fish and shellfish and contact with sediment during recreational activities. The main contaminants of concern are polychlorinated biphenyls (PCBs) and mercury, but they also include arsenic and polycyclic aromatic hydrocarbons (PAHs), among others. Exposure to contaminated seafood and sediment in the LDW was evaluated under various scenarios. Each scenario contains different assumptions that estimate the amount of chemical to which a person might be exposed either by eating fish or through direct contact with sediment. This dose can then be compared with toxicity data to help determine if an exposure is a health hazard.

Conclusions

People who frequently eat resident (nonanadromous) fish and crab caught in the LDW and rockfish from Elliot Bay near Harbor Island may be at some risk for adverse health effects. The primary health concern is the potential for adverse effects on the development of children exposed in the womb. Exposure of the fetus to mercury and PCBs has been shown to impair learning and behavior during childhood. Although a consumption advisory for shellfish, bottomfish, and crab currently exists at urban areas along the King County shoreline, including Elliott Bay and the Lower Duwamish Waterway, the advisory has not been well communicated to potentially impacted populations.

- Data regarding contaminants in LDW salmon indicate that PCB levels are lower than in resident fish and similar to those found in salmon from other parts of Puget

Sound. Salmon also contain high levels of omega-3 fatty acids that protect against heart disease and make salmon a desirable fish to eat. However, if consumed at high rates, contaminants in salmon can also increase adverse health risks to the developing fetus. Exposure to PCBs in salmon and other fish can be reduced through proper preparation and cooking.

- Rockfish caught in Elliot Bay near Harbor Island contain elevated levels of PCBs and mercury. Although the presence of rockfish in the LDW is questionable, they are included in the health assessment because area residents may fish both water bodies.
- Crab samples also indicate elevated levels of PCBs and mercury. Although the amount of crab consumption along the river is not known, people have been witnessed catching crabs in the Duwamish; therefore, advice on the risk of crab consumption from the LDW is necessary. Furthermore, the hepatopancreas in crabs can contain very high levels of PCBs. A study of Asian Pacific Islander seafood consumption revealed that a number of people eat the entire crab, including the hepatopancreas.

An indeterminate health hazard exists for people who eat shellfish from the LDW. It is not clear that the LDW can support a significant shellfish harvest. Mussels were the only species of shellfish that were sampled from the LDW, and metals, PAHs, and PCBs were detected in some samples. Other types of shellfish may accumulate contaminants at different rates, but it is not known what species exist or their quantity. Consumption of significant quantities of shellfish may be of concern, and the DOH Food Safety and Shellfish Programs advise against harvesting shellfish from the King County shoreline (including the LDW), except for Vashon-Maury Island (Figure 8), because of general chemical and biological contamination.

Exposure to sediments in the LDW represents no apparent public health hazard. Although sediments in the LDW have been contaminated, direct contact with sediment through recreational and occupational activities is not expected to result in adverse health effects. The contribution of this pathway is minimal relative to the overall exposure of residents who also eat LDW fish.

Exposure to *chemical* contaminants in surface water while swimming represents *no apparent public health hazard*. The King County Water Quality Assessment concluded that there is little risk to swimmers associated with chemical contaminants in LDW water. Outreach efforts have not indicated that swimming is a common practice, but it is important to note that Public Health Seattle and King County (PH-SKC) has a current advisory against swimming near any of the nine combined sewer overflows (CSOs) in the LDW. This advisory is based on potential exposure to pathogens associated with sporadic releases of raw sewage into the river.

Recommendations

Consumption of resident fish, including sole, flounder, perch, and crab, should be limited to one meal per month, especially for pregnant women or those considering pregnancy. Consumption of rockfish from Elliot Bay near Harbor Island should be avoided. Finfish consumers should eat skinless, cooked fillets and avoid consuming other parts of the fish, particularly the liver. The

hepatopancreas of crabs should not be eaten because of the tendency of this organ to concentrate PCBs. People who eat a lot of fish as part of their regular diet should avoid eating LDW resident fish altogether.

Salmon are the preferred species of fish to eat from the LDW because they are relatively low in contaminants and have high levels of beneficial fatty acids. Salmon should continue to be eaten; however, pregnant women or those considering pregnancy should be aware that even salmon have levels of contaminants that can be detrimental to the developing fetus if consumed on a daily basis. DOH is currently evaluating PCB exposure from consumption of salmon caught throughout Puget Sound, and more specific advice about salmon may be forthcoming.

Further evaluation of the extent of contamination in some fish, shellfish, and crab species is needed to adequately assess exposure from consumption of these species caught in the LDW. However, DOH Food Safety and Shellfish Programs advise against harvesting shellfish from the King County shoreline, except for Vashon-Maury Island (Figure 8), because of general chemical and biological contamination.

- Additional sampling of some species is necessary for adequate assessment of the current advisory and evaluation of the need for a more specific advisory that could include consumption limits.
- Any additional environmental data that is collected will be evaluated by DOH.

Signs communicating the fish/shellfish advisories should be placed at fishing access locations. Additional advisory signs with translation in several languages, including new Spanish and Russian translations, will be posted at several areas along the river. Educational/interpretive signs will be placed at three popular fishing locations: Spokane Street Bridge, Terminal 105, and Herring House Park.

Educational information materials should be provided to populations potentially impacted by LDW contamination. This information should communicate the existing health advisory and communicate the findings of this public health assessment.

- DOH has provided and will continue to provide health information materials, follow-up health education activities, and results of this health assessment to the community. Groups previously contacted for their community health concerns will be the primary audience.

The effectiveness of advisory signs and communications should be assessed over time in order to determine if the message is reaching and staying with the affected community.

Background

This public health assessment was prepared for the Lower Duwamish Waterway (LDW) site by the Washington State Department of Health (DOH) under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). This health assessment is mandated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The LDW site was proposed for listing on the National Priorities List (NPL) on December 1, 2000, in accordance with Section 105 of CERCLA, 42 U.S.C. 9605.² ATSDR is required to conduct a public health assessment for all hazardous waste sites proposed for inclusion on the National Priorities List. On September 13, 2001, the LDW site was officially listed on the NPL by the US Environmental Protection Agency (EPA). The NPL is EPA's list of the nation's most contaminated hazardous waste sites, also known as Superfund sites.

The purpose of this assessment is to determine whether the site poses a public health threat as well as make recommendations and take appropriate actions based on that determination. While a risk assessment conducted under EPA's Remedial Investigation/Feasibility Study (RI/FS) process is used to support the selection of a remedial measure at a site, the public health assessment (PHA) is a mechanism used to provide the community with information on the public health implications of a specific site, identifying those populations for which further health actions or studies are needed.³ Therefore, different assumptions and methods may be used in these studies to reflect their different purposes.

A. Site Description and History

The LDW site is located in King County, Washington on the south shore of Elliott Bay. It consists of nearly 6 miles of the Duwamish River, beginning at the south end of Harbor Island and extending south, just beyond Turning Basin #3. The LDW has served as Seattle's major industrial corridor since it was first created by widening and straightening of the Duwamish River (and formation of Harbor Island) by the US Army Corps of Engineers from 1913 to 1920.⁴ Over 90 years of intense industrial use has resulted in extensive contamination to sediments and some fish species.

Past and current commercial and industrial activities identified at the site include cargo handling and storage, marine construction, boat manufacturing, marina operations, paper and metal fabrication, food processing, and airplane parts manufacturing. The site includes over 15 National Pollutant Discharge Elimination System (NPDES) permit holders and over 100 properties that are listed on Ecology's Confirmed and Suspected Contaminated sites.⁵ In addition, there are over 100 storm drains, combined sewer overflows (CSOs), and other miscellaneous outfalls.¹ These activities have resulted in considerable chemical releases into the LDW over the past 90 years. Sources of contamination include spills and leaks from industrial facilities, industrial operations, waste disposal practices, surface water runoff, storm drain discharge, groundwater discharge, erosion of contaminated soils, atmospheric deposition of industrial air emissions, and combined sewer overflows. Nine CSOs within the LDW study area discharge over 300 million gallons of storm water. Raw sewage is released through these CSOs when waste water treatment plants reach capacity during periods of heavy rain.⁶

The LDW site is currently being co-managed by EPA and the Washington State Department of Ecology (Ecology) under federal CERCLA and state Model Toxics Control Act (MTCA) mandate. EPA is coordinating site investigation activities, while Ecology provides oversight on upland source control activities. Four potentially liable parties collectively known as the Lower Duwamish Waterway Group (LDWG), including the Port of Seattle, King County, City of Seattle, and the Boeing Company, are working with EPA and Ecology to investigate the nature and extent of chemical contamination in LDW sediments and to evaluate cleanup alternatives.

The Duwamish River discharges into Elliott Bay, a deep saltwater port within Puget Sound. Tidal influence extends as far as 13 miles upstream. Surface water in the Duwamish River is primarily fresh or brackish, while deeper water contains more salt. A salt wedge has been documented 10 miles upstream from Elliot Bay. The Duwamish River is approximately 200 feet wide and 30 feet deep below the First Avenue South Bridge, and 150 feet wide and 15–20 feet deep upstream of the bridge. The river is more shallow upstream as a result of less frequent dredging activities.

Harbor Island (another Superfund site listed on the NPL in 1983) is located at the mouth of the Duwamish River, just north of the northern boundary of the LDW. Harbor Island has been extensively utilized for commercial and industrial activities, including ocean and rail transport operations, bulk fuel storage and transfer, secondary lead smelting, fabrication, shipbuilding, and metal plating. Contaminant sources on Harbor Island included storm drains, groundwater seepage, non-point discharges, atmospheric deposition, direct discharge of waste, and historical disposal practices.

Several environmental investigations have been conducted within the LDW study area. Environmental sampling has included analysis of fish, shellfish, crab, and sediments. Water quality sampling has also been conducted to evaluate municipal, commercial, and industrial discharges into the LDW.⁷

The Remedial Investigation (RI) for the LDW site is being conducted in two phases. The objectives of the first phase are to evaluate, compile, and summarize existing data collected during historical environmental investigations; to use existing data to conduct a scoping-phase human health and ecological risk assessment; to identify locations within the LDW where early cleanup actions may be suitable; and to identify data gaps and prepare a work plan to complete the RI.⁸ To date, the LDWG has prepared an initial RI and has identified several sites along the LDW that have been slated for early cleanup. The objectives of the second phase are to conduct additional studies to fill data gaps, to prepare a baseline ecological and human health risk assessment, and to estimate residual health risk associated with completed or planned early cleanup actions.

A large data set exists for sediment chemistry within the LDW (over 1,200 surface sediment samples); however, sediment samples near public access points are limited. Existing data regarding contaminant concentrations in fish, shellfish, and crab tissue are limited. The scoping-phase human health risk assessment for the LDW is based upon existing environmental data; it is intended to determine if contaminants in sediment from the LDW represent a human health hazard as a result of seafood consumption, dermal contact, and incidental ingestion of contaminated sediments. Data gaps identified in the scoping-phase human health risk assessment

will be filled prior to conducting the baseline human health risk assessment during the second phase of the RI.⁹

B. Site Visits

DOH representatives conducted a number of site visits in the summer of 2001 and the spring and summer of 2002 in conjunction with various representatives of federal, state, and local environmental agencies, coalitions, environmental groups, and the general public. Site visits included taking boat tours, walking portions of the shoreline, and visiting area neighborhoods. cursory inspection of the area surrounding the site was also conducted by driving around the entire perimeter in an automobile.

During boat tours, a number of observations were made, and site photos were collected by use of a digital camera (Appendix B). Observations focused on potential human access points along the LDW shoreline, including boat launches, fishing piers, or areas that would accommodate fishing or other recreational activities. During the site visits, it was noted that a number of streets end at the shoreline, providing access to the river.

Several people were observed fishing and walking the shoreline at Duwamish River Park, and on one occasion, people were observed swimming in the LDW. Commercial fishing nets set for salmon were seen north of South Park Marina. Many shoreline areas along the LDW were easily accessible, and individuals were observed walking, jogging, and picnicking along trails that run parallel to the waterway.

C. Demographics, Land Use, and Natural Resources Use

Demographics

The City of Seattle has a population of 563,374, and the entire population of King County is 1,737,034. These population figures are based upon 2000 census data and represent an increase of 9.1 and 15.2 %, respectively, over the 1990 census population numbers.

The LDW study area extends through both the South Park and Georgetown neighborhoods of south Seattle. The South Park neighborhood is defined as census tract 112, and Georgetown is defined as census tract 109.¹⁰ The South Park and Georgetown neighborhoods are both located within the postal zip code area 98108; they have a combined population of approximately 4,900. Population in Georgetown (Census tract 109) has decreased slightly since 1990, while South Park's (tract 112) population has increased by nearly 32 %. Table 1 shows the changes in population between 1990 and 2000.

Table 1. Comparison of 1990 and 2000 population for Census Tracts 109 (Georgetown) and 112 (South Park) King County, Seattle, Washington.¹¹

	Census Tract 109 (1990 Census)	Census Tract 109 (2000 Census)	Census Tract 112 (1990 Census)	Census Tract 112 (2000 Census)
Total:	1,238	1,181	2,809	3,717
White	856	724	1,874	1,626
Black or African American	102	78	238	312
Hispanic or Latino	152	174	420	1,379
American Indian and Alaska Native	79	30	96	74
Asian	121	163	365	524
Native Hawaiian and Other Pacific Islander	N/A	19	N/A	51
Some other race	80	98	236	916
Multiracial	N/A	69	N/A	214

Land Use

Zoning along the LDW study area includes residential, commercial, residential/commercial, neighborhood commercial, and industrial. Shoreline zoning includes conservancy recreation, conservancy preservation, and urban industrial use. Upland areas adjacent to the LDW are heavily industrial and commercial, but they also support residential use.

Although the majority of land use and zoning in the LDW corridor is industrial, there are two mixed residential/commercial neighborhoods adjacent to the study area.¹⁰ The South Park neighborhood is located in the southern city limits of the City of Seattle, bordering the west side of the LDW.¹⁰ The Georgetown neighborhood is located east of the LDW and is separated from the site by several commercial facilities between the waterway and East Marginal Way South.¹⁰

Natural Resource Use

The LDW is a major shipping route for containerized and bulk cargo. A portion of the LDW site is maintained by the US Army Corps of Engineers as a federal navigation channel supporting intensive marine traffic.

The Muckleshoot Tribe commercially harvest salmon (chinook, coho, chum, winter and summer steelhead) from the LDW. The LDW also abuts the usual and accustomed (U & A) fishing area for the Suquamish Tribe. In addition, recreational fishing for salmon and bottomfish is prevalent within the area, and subsistence fish consumption among various populations has also been reported.¹² A number of water-related recreational activities occur in the LDW, including swimming, kayaking, wading, and scuba diving.

Approximately 10 million juvenile salmon migrate through the LDW annually. A number of studies conducted by the National Marine Fisheries Service (NMFS) indicate that juvenile

salmon from the LDW exhibit reduced growth and immune system function. In contrast, a recent study concluded that chronic dietary exposure to PCBs did not have an effect on growth and disease resistance in juvenile chinook salmon in conditions relevant to the LDW.¹³ Several habitat restoration activities have occurred at the LDW site, including the recent Herrings House Park restoration project (17 acre wetland) that provides refuge for salmon migrating downstream through the LDW. The LDW serves as a migratory route and transition zone for Pacific salmon. Chinook salmon, federally listed as a threatened species, use the LDW during a critical stage of migration.

Community Health Concerns

Community members expressed a number of health concerns relating to the LDW site. Specific health concerns are outlined and individually addressed in the Community Health Concerns Evaluation section of this public health assessment. The following is a discussion of strategies used to connect with ethnically diverse communities surrounding the LDW and the health concerns that were gathered. It is organized chronologically, outlining activities and community groups that were contacted by DOH during community outreach activities.

Summary

Community outreach and education is an essential component of the public health assessment process. The community outreach educator's initial responsibility is to contact people who may be exposed to contaminants in the river, to find out how they are being exposed, and to learn whether they have any health concerns. Exposure means a person is eating, breathing, or drinking contaminants or else absorbing them through their skin.

Initial outreach efforts dispelled the notion that it was common knowledge that the LDW was polluted and that there is no harvest or consumption of seafood from the LDW. One South Park activist repeatedly insisted that people were consuming seafood from the LDW and that these people were most likely from Pacific Islander or Asian immigrant and refugee communities. Populations who rely on the LDW as a primary source of food prefer to remain anonymous. They often fish without a license to provide food for their families, and many have a deep distrust of government officials. Therefore, the primary community outreach strategy emphasized compassion followed by education. DOH made over two hundred phone calls to community organizations to find key community leaders from Asian/Pacific Islander populations who were willing to assist with coordination and communication activities. The key to reaching these populations was to allow community leaders to offer their own strategies for connecting with their people and then incorporating and implementing their ideas.

Outreach Strategy

Connecting with culturally diverse, non-English speaking communities requires outreach that goes beyond traditional methods such as meetings sponsored by government agencies, informational mailings, and press releases. Meeting with community groups on their own terms demonstrated sincerity and built trust. Arranging to meet community members at meal sites (meals organized at community centers for seniors or other community members), where many

congregate weekly to socialize and have lunch, proved an excellent way to initiate communication. Some communities participate in monthly evening meetings at an individual's home or at a neighborhood community center. Focus groups hosted by a community leader and a local interpreter are also effective. Such interaction with the community builds credibility that is essential for healthy interactive relationships and that establishes the foundation for health education activities.

DOH conducted an extensive community outreach campaign in conjunction with the preparation of this public health assessment. Various outreach approaches included meeting groups at meal sites, arranging focus groups through Public Health-Seattle & King County (PH-SKC), attending community events, participating in river tours, and talking one-on-one with community leaders and community representatives. Health concerns and feedback for future outreach activities were gathered from Cambodian, Vietnamese, Filipino, Hmong, Laotian, Tongan, Hispanic, Native American, and white members of the South Park and Georgetown neighborhood communities. Concerns and opinions were also collected from environmental groups involved in river restoration, from state representatives, from business leaders, and from a Washington State Fish and Wildlife Conservation officer. A complete description of community involvement activities is given below

One-on-One Community Interviews

During March and April of 2001, representatives from DOH, EPA and Ecology began conducting one-on-one interviews with community members, community leaders, state representatives, business leaders, environmentalists, tribal members, and community activists. Individuals who were interviewed had either indicated an interest by responding to a request from EPA or else were identified as interviewees because of past involvement with the LDW site. During this time period, over 35 community interviews were conducted at EPA or at locations within the Duwamish corridor. In some cases, interviews were conducted via conference call. A set of questions was administered to interviewees and responses to questions were summarized and listed in EPA's community involvement plan.

Concerns expressed included:

- Health hazards of fish consumption (particularly salmon).
- Respiratory problems.
- Reaching the Spanish-speaking neighbors.
- Health hazards of dermal contact with sediments.
- Health risks during cleanup work parties.
- Staff turnover within government agencies.
- Health hazards of fish consumption among Southeast Asian and Native American populations.
- Subsistence fishing in the river.
- Litigation and delays in cleanup.
- Health hazards of children playing in the sediments and the water.
- Cumulative effects of exposure to contaminants from different sources in the community.
- Quality of life and mortality rates in the community.

- Connections between contaminants and cancer and lung disease.
- Health hazards to unborn children and women of childbearing age.
- The safety of fish sold in markets.
- Data not being shared, communicated, or made publicly available.

Public Availability Session

On May 24, 2001, DOH organized an availability session at Concord Elementary School, located in the South Park Neighborhood, to gather community health concerns. Over 600 invitations were mailed to local residents and businesses. There was considerable agency participation from DOH, PH-SKC, EPA, and Ecology. However, the session was not attended by any nonbusiness members of the community. As a result, DOH used other methods to communicate with populations potentially impacted by contamination within the LDW site.

Hispanic Community

A public health educator from PH-SKC organized two Hispanic focus groups through the SeaMar Community Health Center to explore how the Hispanic community may be using the LDW. Both meetings were held at the SeaMar Community Care Center. Many of the group participants live within and around the South Park neighborhood and utilize SeaMar for personal and family medical care. The initial focus group was held August 14, 2001, and the second group was held the following evening. A combined total of seventeen individuals participated in the focus groups. Several participants indicated they walk along the shore of the LDW and picnic at a park located at the shoreline of the LDW. None of the participants in either focus group fish in the LDW. However, there were reports of “older gentlemen” frequently fishing from the South Park bridge and the Boeing bridge. No health concerns related directly to LDW contamination, but participants were concerned about drinking water quality.¹⁴

On September 20, 2001, the South Park Neighborhood Association (formerly the South Park Crime Council) held its first Spanish-speaking meeting in the 30 years of the Association’s existence. Representatives from DOH and EPA attended this meeting. DOH distributed maps and initiated a discussion about fishing, recreational habits, and health concerns. The representative from EPA outlined her role in the site cleanup process and served as an interpreter. The meeting was held in a beauty parlor on the first floor of a private residence in the heart of the South Park neighborhood.

Thirty adults and several children, in a standing-room only crowd, participated with a high level of interest. Participants expressed frustration that, as a poor community, they feel they are being ignored by government agencies. Meeting participants indicated they were not aware of any contamination problems and do not fish in the LDW. There was concern about children playing in sediments at parks along the river, and participants indicated an interest in assisting with posting signs in local parks. Participants indicated that signs need to communicate in both Spanish and English. Because local parks are frequently used, there was interest in receiving further environmental health education. Language was identified as a barrier to communication between agencies and the community.

On October 24, 2001, DOH met with El Planeta, an Hispanic youth group in the South Park neighborhood led by a representative of the Environmental Coalition of South Seattle (ECOSS). Seven teenagers and four adults participated. An overview of the LDW and potential adverse impacts on human health were discussed, as well as fishing habits of individuals within the neighborhood. The participants stated that they do not fish in the river, but they frequently observe other people (non-Hispanic) fishing in the river. Site location maps were distributed, a shellfish filter-feeding demonstration was provided, examples of shells from shellfish native to the LDW and Elliott Bay were shared, pictures of bottomfish were displayed and discussed, and an example of an advisory sign was presented. The sign uses the word *bottomfish*, and adults explained that there is not a word for *bottomfish* in the Spanish language. Teens each received a handout with questions that will be used to canvass their neighborhood as part of an El Planeta environmental education project.

Asian/Pacific Islander Communities

The Asian/Pacific Islander (API) communities within the Duwamish corridor are very diverse, although many share a traditional diet high in fish and shellfish. API groups expressed similar concerns and are likely to be among high-end consumers of seafood harvested from the LDW. DOH learned from local community leaders and Washington Department of Fish and Wildlife officials that API community members may be subsistence fishing without a license, so that they may be reluctant to admit that they harvest seafood from the LDW. It was difficult to identify API community leaders within the boundaries of the South Park neighborhood. Therefore, it was necessary to expand into surrounding neighborhoods with community centers that serve the API target populations. As a result of this strategy, DOH learned that many groups that fish in the Duwamish river do not necessarily live in neighborhoods adjacent to the river. Additionally, because word-of-mouth is often a very effective way to communicate in immigrant communities, participants were asked to spread the word about the existing Duwamish fish advisory to their families and friends. Common themes expressed by community members included concern about safety of consuming salmon harvested from the LDW and how to be certain that seafood purchased in markets is safe to eat. The second concern is addressed in the Community Health Concerns Evaluation section (question 2) of this health assessment.

PH-SKC organized two Vietnamese focus groups to explore how the Vietnamese community uses the LDW. A Vietnamese outreach worker was retained to assemble both focus groups. One woman, her husband, and a colleague, all of whom are very active and respected within the Vietnamese community, assisted. These individuals were able to use personal contacts, existing clinic lists, and door-to-door requests to solicit participation in focus groups. The first focus group was held on August 9, 2001. There were eleven participants—six men and five women—from the vicinity of the High Point Housing community in west Seattle. Several of the women had young children, and childcare was provided. The second focus group, held on August 11, 2001, consisted of four women and five men. Most of the men were senior citizens, while the women were younger. All but one of the participants lived in the Rainier Vista Housing community.¹⁴

All participants in both groups were aware of the LDW, several had fished there, and all were aware of people who either fish or consume fish harvested from the LDW. Crab and flounder are

some of the species consumed from the waterway. One participant indicated that a relative fishes and eats fish harvested from the LDW daily. A single person indicated that he eats fish and/or shellfish from the LDW once a week, and another individual consumes seafood from the area about once a month. People said they like to eat fish heads, stomachs, and eggs. One participant's nephew fishes and gives the fish away to family members. Another participant knows someone who fishes in the LDW and sells to a local fish market. One woman indicated she recently consumed a crab (which she often does) from the LDW and described the crab as "muddy and oily", even though she cleaned it well. She said the flesh was bitter and that she later became sick to her stomach but did not seek medical attention. Vietnamese participants were very concerned that they had no previous knowledge of LDW pollution. Both groups agreed that if there is a concern about the river, the information needs to be shared with the community. Neither group was aware of signs communicating any type of a warning.¹⁴

On September 27, 2001, the Pacific Asian Empowerment Program (PAEP) in Seattle arranged for DOH to provide a presentation with questions and answers at a senior citizen meal site in the local Filipino Community Center. Approximately 50 people attended, including several community leaders. All participants spoke English, and therefore no translators were necessary. Each participant received a DOH booklet entitled "Public Shellfish Sites of Puget Sound" as well as a shellfish-shaped magnet printed with the DOH 1-800 shellfish hotline telephone number and Web-site address. This group was well-educated and organized. DOH received a very warm reception, and everyone indicated eating shellfish and seafood because it represents a large part of their original island culture. Some individuals indicated consumption of fish heads, livers, and other organs. Three men admitted they fish within the LDW and wanted to know if it was safe to consume salmon from there. Questions arose relating to the safety of consuming seafood from local markets and what type of fish, if any, are safe for consumption. This group was very interested in signs' being posted along the LDW shoreline regarding the existing health advisory and was very interested in follow-up environmental health education.

On September 28, 2001, the PAEP arranged for a DOH presentation, with questions and answers, to the Hmong and Laotian community at a meal-site at the Brighton Presbyterian Church on 51st Avenue. Two translators from the community provided interpretation in the Laotian and Hmong languages. About 35 people joined in the discussion, which included a shellfish filter-feeding demonstration. The church has a Vietnamese pastor, and participants were primarily elderly, but there were several younger adults and some small children in attendance.

The Hmong were a mountain-dwelling people in their homeland, and the Laotians originally lived in land-locked communities. Many people did not know where the LDW was located and were not sure if they had ever been there. One man reported that he has fished in the LDW, and a few people mentioned that they fished in Lake Washington. The immediate question was why signs were not posted within the LDW if there is a pollution problem. This group does eat fish and shellfish from the LDW, but members primarily purchase seafood from local markets. The other immediate question related to whether fish and shellfish at local markets were safe. This population agreed to spread the word within their communities regarding the existing health advisory for the LDW. There were no human health concerns expressed, because until the presentation, they were not aware of any problem.

On October 11, 2001, DOH met with a Tongan (Pacific Islander) community group during a monthly community meeting in Burien, Washington. A variety of maps and large pictures of fish species reportedly harvested from the LDW were used as visual aids. All participants spoke English, so that an interpreter was not required. There was concern about consumption of salmon from the LDW and questions regarding its safety. Participants want to know if seafood at the markets is safe to eat and what precautions are taken to ensure food safety. They do not eat fish organs, and they want to learn more about shellfish harvesting. This group agreed to spread word of the existing health advisory to family and friends. Group members did not have health concerns because they were not aware of a problem until the meeting.

On November 9, 2001, the PAEP arranged for DOH to meet with Samoan senior citizens at a meal-site at the Rainier Community Center. Seven people participated in the meeting. Most of the Samoan seniors were familiar with the Duwamish River. They stated that many people fish there, but they do not know these people personally. The elders were concerned about the safety of salmon. They agreed to spread word of the existing advisory to their communities. One woman had friends who live in the South Park neighborhood. Group members also requested that DOH return with the results of the public health assessment. The Samoan coordinator for this meal site told DOH that the people who live in the South Park neighborhood are Tongan, not Samoan. She knew other Samoan groups that fish and would be interested in a public health message regarding the Duwamish Waterway. She agreed to help DOH meet with them when the health assessment is completed.

On October 12, 2001, DOH met with a Cambodian meal-site group consisting of approximately 30 adults and several children at their Friday brunch at the Park Lake Community room in White Center. A variety of maps and large pictures of fish and shellfish species were used as visual aids. Most participants did not speak English, and the hosting community leader offered his services as an interpreter. No one would acknowledge fishing in the LDW, but all were aware of its location. This group consumes fish eggs but does not eat fish organs. The safety of market-bought seafood was a common concern. The group questioned whether seafood would be safe to harvest after the LDW is cleaned up and how long the cleanup would take. There was interest in learning about safe-harvesting techniques. This group agreed to spread word of the existing health advisory to friends and family members but did not have health concerns because they were not previously aware of contamination in the LDW. After the presentation and discussion, the interpreter mentioned that several people fish in the LDW to feed their families. The interpreter also indicated that a video in their own language may be a useful method for health education.

DOH met with a second Cambodian meal-site group on October 17, 2001, at a brunch located at the YMCA in the High Point neighborhood. Approximately 28 adults and a few children participated. Two of the adults had been present at the Cambodian brunch in White Center the previous Friday. Most participants did not speak English, and the hosting community leader served as an interpreter. Everyone knew where the LDW was located, but group members would not say if they fished there. The group wanted to know if seafood at markets is safe and, if so, how the safety of market fish is ensured. Concern about salmon caught in the LDW was also identified. Participants want to learn more about safe harvesting and agreed to spread word of the existing advisory to their families and friends. They also did not have health concerns because

they did not know there was a contamination problem until that time.

Tribal Issues

DOH values tribal participation. The Suquamish, Muckleshoot, and Duwamish Tribes are deeply invested in the Duwamish River for harvesting, cultural, and spiritual purposes. Although the Duwamish Tribe is not currently recognized by the federal government, DOH acknowledges the tribe's extensive cultural involvement with the river. Tribal health concerns are discussed below.

Muckleshoot Tribe

On June 26, 2001, DOH met with a representative and biologist for the Muckleshoot Tribe to discuss fishing habits and health concerns related to the LDW site. The Muckleshoot Tribe is particularly concerned because the site comprises a significant area of their U & A fishing grounds as guaranteed by federal treaty law. The Tribe expects EPA to provide maximum protection of these grounds. The Muckleshoot Tribe is primarily concerned about the following:

- Dermal contact with contaminated sediments as tribal members are checking fishing nets.
- Occupational exposure to fishermen exercising their treaty rights.
- Understanding the implications of risk associated with consumption of adult salmon.

Duwamish Tribe

DOH met with a tribal leader from the Duwamish Tribe on July 6, 2001, to gather health concerns and perspectives on fishing habits. The Duwamish Tribe believes in using traditional, not modern, fishing methods. The Duwamish Tribe is especially concerned about the following:

- Frustration because the process of completing a public health assessment takes a significant amount of time.
- Establishing consistent relationships with agencies involved in LDW cleanup activities (the Duwamish Tribe prefers to communicate with the same individuals over time).
- Fear that government agencies are afraid to approach issues regarding the LDW because of the industrial corridor.
- General human health effects of eating fish from the LDW.
- Cancer and leukemia from eating fish from the LDW.
- The health of new immigrants (specifically South East Asian) who fish on the river to feed their families.
- Mishandled resources, particularly the fishery.
- Methods of sediment core sampling.
- Raw sewage discharged into the waterway.

Suquamish Tribe

On April 15, 2002, DOH met with the Suquamish Tribal biologist, the Environmental Program Manager, and the Fisheries Policy Liaison to discuss the tribe's health concerns related to the

Duwamish River. The meeting was held at the Suquamish Tribe's offices. DOH staff had recently attended a program of the Governor's Office of Indian Affairs, "Government to Government Training", to learn more about tribal perspectives.

The tribe members stated that they take the seven-generation approach to natural resource management. The tribe considers Elliott Bay and the Duwamish River to be part of their U&A fishing area. The tribe currently fishes commercially for salmon up to the Spokane Street Bridge (the mouth of the Duwamish). Fishers may keep other species for family consumption while fishing for salmon. The tribe is very concerned about pollution and wants children's exposures to contaminated sediments while net-fishing to be considered. The following are the Suquamish Tribe's primary health concerns:

- The future of shellfish harvesting in the Duwamish River.
- Sewer outfall and raw sewage problems.
- Tumors in fish.
- Cancer.
- Safety of consuming resident fish and shellfish (species that do not migrate).
- Exposures to children fishing with their parents.
- The dramatic increase in diabetes and other health problems that result when native people decrease their seafood consumption and substitute it for less nutritious food items.

South Park Neighborhood Association

On April 9, 2002, the DOH Community Outreach Educator met with the South Park Neighborhood Association (formerly the South Park Crime Prevention Council). Approximately 25 people attended the meeting. All attendees were white except for one African-American teen. The emphasis of the meeting was on teen recognition and service in the community. The second half of the meeting was devoted entirely to crime prevention issues. DOH encouraged teen participation in community outreach messages regarding the Duwamish River and welcomed input from meeting participants. Maps as well as a toll-free contact number were distributed. When questioned about the Duwamish River, members stated that they do not fish or swim in the river. Three people kayak in the river, four people have pets that swim in the river, and four raised their hands when asked if they have contact with sediments in the parks along the water. Members expressed concern regarding receiving prompt notification should a health hazard be determined to exist at the Duwamish River site.

Cleanup Coalition River Tour

The Duwamish River Cleanup Coalition (DRCC) is comprised of the People for Puget Sound, the Puget Soundkeeper Alliance, the Waste Action Project, the Environmental Coalition of South Seattle, the Duwamish Tribe, the Green-Duwamish Watershed Alliance, the Washington Toxics Coalition, the Georgetown Community Council, and the Community Coalition for Environmental Justice. The DRCC sponsored a boat tour of the LDW on September 8, 2001. DOH was invited to attend in order to interview individuals regarding potential health concerns, particularly the concerns of those who may be directly involved in restoration work along the LDW and who may be exposed to contaminated sediments. Approximately 40 people

participated in the boat tour. Seven people expressed interest in the public health assessment but had no human health concerns to report.

South Park Marina

Two DOH representatives were available from 9 AM to noon at the South Park Marina on August 25, 2001. The purpose of this activity was to collect health concerns from marina users regarding the LDW site. Flyers were prominently posted on marina property by the manager one week prior to the availability session. A large aerial photo and map of the LDW site, informational handouts, and a table and chairs were set up outside the office of the South Park Marina. The marina manager was very knowledgeable about the site and supportive of DOH's presence. Flyers were also sent to the manager of the Duwamish Yacht Club for distribution prior to the event. A local activist and marina tenant advocated participation to marina tenants prior to August 25 and met with DOH at the marina on the day of the availability session.

Seven people spoke with DOH staff and asked questions and shared their health concerns. The community activist believes that people he spoke with previously are overwhelmed by the magnitude of the LDW site and prefer to remain anonymous and not receive more bad news about contamination present in the LDW. Distrust of government, fear, and weariness may be hindering communication with some marina tenants. Five of the respondents were middle-aged white men, and the other two were a retired couple that live adjacent to the marina. No human health concerns regarding the LDW site were documented during the session. Most of the participants had some knowledge about the site, and all were very interested in the cleanup process. One tenant expressed the desire for "a clear message" and "just tell me what I need to know." No feedback was received from marina users at the Duwamish Yacht Club.

Interview with Washington Department of Fish and Wildlife Enforcement

On October 3, 2001, DOH conducted a telephone interview with an enforcement officer for the WDFW responsible for patrolling the LDW study area. The enforcement officer indicated that he has observed approximately 20–30 people fishing in the area (mostly Asian, a couple of Hispanics, and a few Russians). Several men enjoy fishing in the middle of the night. Salmon fishing is popular during late summer and fall. The enforcement officer has observed people fishing from the following locations: Spokane Street bridge near the south end of Harbor Island (shiner perch, flounder, herring, Dungeness crab, red rock crab, graceful crab, sculpin, and squid); Terminal 105 bridge (shiner perch, flounder, and herring); Highway 99 bridge (barred perch and flounder); railroad bridge (Dungeness crab, red rock crab, graceful crab); and Kellogg Island (fresh water clams/mussels). These locations are identified in Figure 4.

Russian and Ukrainian Communities

DOH made several attempts to contact the Russian community through refugee/immigrant organizations, social workers, food banks, churches, and housing developments. An appointment to meet with a Ukrainian church group in White Center on October 14, 2001, was canceled by the pastor. An extreme distrust of government agencies exists within the Russian and Ukrainian

communities. Community leaders are interested in health messages but are reluctant to meet with government agency staff.

On November 8, 2001, DOH and PH-SKC met with a Russian/Ukrainian translator who immigrated to the United States from the Chernobyl area in 1998. The translator explained that people from the former Soviet Union are very fearful of government and of punishment by the government. She described it as “genetic fear.” She stated that many immigrants find refuge in Pentecostal religion and are a very closed people. The prevailing attitude is “we have our culture and you have yours.” The belief is that the less that is known about them, the less they can be manipulated and hurt. The translator agreed to help DOH and PH-SKC communicate with Russian and Ukrainian groups if the agencies establish a connection with a community leader.

Environmental Contamination

A. Introduction

A considerable amount of chemical and biological contaminants has been released into the LDW over the past 90 years. Contaminants move to the river through surface water runoff, storm drain systems, combined sewer overflows, permitted industrial discharges, and non-point source runoff from commercial and industrial operations. The resulting contamination has contributed to the process of bioaccumulation in fish, shellfish, and crab. Bioaccumulation varies considerably with respect to the type of contaminant and the affected species.¹⁵

B. Contaminants of Concern

Tables 3 and 4 below list contaminants of concern (COCs) for each completed exposure pathway. Each contaminant is compared with a health comparison value (i.e., screening value) to see if it is occurring at a high enough level to warrant further consideration. If a contaminant exceeds its health comparison value for a specific media (e.g., fish, shellfish, or sediment), it is evaluated further under the Pathways Analysis/Public Health Implications section. The fact that a contaminant exceeds its

health comparison value does not mean that a public health concern exists; rather, it signifies the need to consider the chemical further. The health comparison values used in this public health assessment include screening values in fish from EPA guidance,¹⁶ environmental media evaluation guides (EMEGs), cancer risk evaluation guides (CREGs), reference dose media evaluation guides (RMEGs), EPA Region 9 Preliminary Remedial Goals (PRGs), and Model Toxics Control Act (MTCA) cleanup values for soil. Appendix F explains the screening process in detail.

Also included in the COC tables are EPA’s weight-of-evidence cancer classifications for each contaminant. This classification scheme will be revised in the near future but currently consists of six groups: 1) Group A—Known Human Carcinogen, 2) Group B1—Probable Human

Contaminants of Concern

Contaminants of concern (COCs) are those chemicals found at the site that *may* cause health effects. Not all chemicals found at the site are COCs and not all COCs are health hazards. COCs found in sediment and fish/shellfish are evaluated in the Pathways Analysis/Public Health Implications section.

Carcinogen with sufficient animal data and limited human data, 3) Group B2—Probable Human Carcinogen with sufficient animal data and inadequate or no human data, 4) Group C—Possible Human Carcinogen, 5) Group D—Not Classifiable as to Human Carcinogenicity, and 6) Group E—Evidence of Noncarcinogenicity in Humans

1. Fish/Shellfish

A number of fish species are harvested from the LDW study area by subsistence and recreational consumers. For purposes of evaluating the fish consumption pathway, target species were selected in order to assess contaminant concentrations in different fish groups. Chinook and coho salmon were evaluated as part of the anadromous group, English sole was selected to represent bottomfish, and perch was used as a surrogate for the pelagic group. Quillback rockfish were also evaluated because of high levels of PCBs and mercury detected in samples from Elliot Bay near Harbor Island, although it is not clear whether this species is present in the LDW. Red rock and dungeness crab were also evaluated because of information that these species are consumed from the LDW. Table 2 shows the type and quantity of fish samples that were used to characterize fish populations in the LDW.

Table 2 - Distribution of fish sample analyses by species used in the health assessment of the Lower Duwamish Waterway site, Seattle, Washington.^a

Species	Composite	Individual	Total Number of Fish or Shellfish	Sample Location
Chinook	31	34	171	See Figure 2f
Coho	44	1	205	See Figure 2f
English Sole	18	3	164	See Figure 2a
Striped Perch	8	1	52	See Figure 2b
Rockfish	0	5	5	See Figure 2e
Mussels	0	63	63	See Figure 2d
Dungeness Crab	0	3	3	See Figure 2c
Red Rock Crab	9	0	45	See Figure 2c

a = Sample numbers are based on analysis for total PCBs

Contaminants that exceeded comparison values are presented in Table 3 as contaminants of concern(COC) requiring further evaluation. Comparison values are screening values, and the listing of a contaminant in Table 3 does not mean that an adverse health effect will result from exposure. Potential health effects from exposure to contaminants listed in Table 3 are evaluated in the Pathways Analysis/Public Health Implications section of this health assessment.

Table 3. Contaminants of concern in fish from the Lower Duwamish Waterway^a

Contaminant	Maximum/Weighted Average								Comparison Value ^b	Cancer Class
	Chinook Salmon	Coho Salmon	English Sole	Quillback Rockfish	Red Rock Crab	Dungeness Crab	Perch ^c	mussels		
Arsenic (mg/kg)	1.4/ 1.0	1.6 0.8	15/ 10	NA	NA	12.5/ 9.9	1.4/ 1.3	1.1/ 0.8	0.003	A
Cadmium (mg/kg)	NA	NA	<0.05	NA	NA	<0.02	NA	0.7/ 0.4	0.5	B1 (inhalation)
Chlordane (ug/kg)	15/ 1.2	2.5/ 0.9	3.4/ 1.1	NA	NA	NA	NA	<7	14	B2
cPAHs (ug/kg) ^d	<50	<47	<49	NA	NA	<29	NA	62/ 42	0.7	B2
DDE (ug/kg)	33.8/ 19.3	17.4/ 8.3	5.3/ 2.7	<0.1	NA	NA	NA	<1.3	14	B2
PCBs (ug/kg)	160/ 51	97/ 36	640/ 267	428/ 292	204/ 110	177/ 130	228/ 111	73/ 29	2	B2
Mercury (ug/kg)	150/ 102	52/ 42	83.0/ 53.6	567/ 408	130/ 63	111/ 90	60/ 15.4	16/ 11	49	NA

a = Values are for chemicals present in skinless fillets or edible tissue unless otherwise noted

b = Comparison values for contaminants in fish were obtained from EPA Guidance for Assessing Chemical Contaminant Data (subsistence fishers)

c = Arsenic level in perch was calculated from 3 whole body shiner perch samples. Other contaminant levels were calculated from skinless striped perch fillets.

d = Carcinogenic Polycyclic Aromatic Hydrocarbons—Benzo(a)pyrene Toxic Equivalent (TEQ)

A Human Carcinogen

B1 Probable Human Carcinogen

B2 Probable Human Carcinogen; inadequate human evidence, sufficient animal evidence

NA Not available

2. Sediment

Approximately 1,200 surface sediment samples have been collected from the LDW study area within the past 10 years. Phase I of the LDW RI compiled all existing sediment data sets for the LDW and applied a defined set of data quality objectives to determine if the data would be included and used in the RI.¹⁷

Surface sediment data from 25 sampling events were included in the database for evaluation in the RI. Surface sediments are defined as sediment less than 15 centimeters (cm) deep, and subsurface sediments are defined as sediments greater than 15 cm deep. Approximately 400 surface sediment samples were collected from intertidal areas along the LDW, and the remainder were collected from subtidal locations. Intertidal areas are those that are submerged during high tide and exposed during low tide.

It should be noted that these data were provided to EPA and Ecology in October 2001 for quality assurance review, and those data are still being evaluated by both agencies at the time this public health assessment was prepared. The sediment data set for the LDW will be re-evaluated by DOH following final review by EPA and Ecology.

Contaminants of concern in LDW sediments are shown in Table 4. The screening process used to select COCs in sediment is described in Appendix F. Although concentrations of mercury, cadmium, DDE, and chlordane in sediment were below comparison values, they were included as contaminants of concern to be evaluated in conjunction with the fish consumption pathway.

Table 4. Contaminants of concern in sediment at the Lower Duwamish Waterway site located in Seattle, Washington

Contaminant	Average Concentration	95 th Percentile Concentration	Comparison Value	Source
Arsenic (mg/kg)	14	30	20	EMEG
Cadmium ^b (mg/kg)	1.2	2.8	10	EMEG
Chlordane ^b (ug/kg)	10	37	2000	CREG
DDE ^b (ug/kg)	5	12	2000	CREG
Mercury ^b (mg/kg)	0.29	0.64	5	RMEG ^a
cPAH's ^c (ug/kg)	0.52	1.4	0.1	CREG
Polychlorinated Biphenyls (PCB's) (ug/kg)	2203	4406	400	CREG

a = RMEG is for methyl mercury

b = Contaminants were included in list of sediment COCs due to fish consumption pathway

c = Carcinogenic Polycyclic Aromatic Hydrocarbons—Benzo(a)pyrene Toxic Equivalent (TEQ)

C. Quality Assurance and Quality Control

This public health assessment relies upon information provided in the referenced documents and assumes that adequate quality assurance and quality control measures were followed regarding chain of custody, laboratory procedures, and data reporting. The validity of the analysis and conclusions drawn in this public health assessment is dependent upon the completeness, relevance, and reliability of the referenced information.

D. Physical Hazards

Among the physical hazards within the LDW study area are riprap, rubble, storm drains, sewer outfalls, and elevated shoreline access points without railings. The waterway is heavily used for cargo transport by commercial vessels that may pose a hazard to recreational users of the waterway. In addition, there are physical hazards such as debris, glass, and unstable rock and riprap materials that could represent a concern. Physical hazards are not quantified in this public health assessment.

Pathways Analysis/Public Health Implications

A. Introduction

The following section discusses various COCs, how people might come into contact with these contaminants, and the potential health effects that may result. In order for an exposure to these contaminants to occur, all the elements of an exposure pathway must be in place. Exposure pathways are categorized as “completed” and “potential”, and they can be current, past, or future. A completed exposure pathway consists of five elements: 1) a source, 2) an environmental media/transport, 3) a point of exposure, 4) a route of exposure, and 5) a receptor population. A potential exposure pathway exists when some but not all of these five elements are present and the potential exists that the missing elements have been present (past), are present (current), or will be present (future). The completed and potential exposure pathways for the LDW site are given in Tables 5 and 6 below. Each pathway is then discussed in terms of the contaminants of concern and the potential health hazard posed.

Evaluating Noncancer Risk

In order to evaluate the potential for noncancer adverse health effects that may result from exposure to contaminated media (i.e., air, water, soil, and sediment), a dose is estimated for each contaminant of concern. These doses are calculated for situations (scenarios) in which nearby residents might come into contact with the contaminated media. The estimated dose for each contaminant under each scenario is then compared to ATSDR’s minimal risk level (MRL) or EPA’s oral reference dose (RfD). MRLs and RfDs are doses below which noncancer adverse health effects are not expected to occur (so-called “safe” doses). They are derived from toxic effect levels obtained from human population and laboratory animal studies. These toxic effect levels can be either the lowest-observed adverse effect level (LOAEL) or a no-observed adverse effect level (NOAEL). In human or animal studies, the LOAEL is the lowest dose at which an adverse health effect is seen, while the NOAEL is the highest dose that did not result in any adverse health effects.

Because of uncertainty in these data, the toxic effect level is divided by “safety factors” to produce the lower and more protective MRL or RfD. If a dose exceeds the MRL or RfD, this indicates only the potential for adverse health effects. The magnitude of this potential can be inferred from the degree to which this value is exceeded. If the estimated exposure dose is only slightly above the MRL or RfD, then that dose will fall well below the toxic effect level. The higher the estimated dose is above the MRL or RfD, the closer it will be to the actual toxic effect level. This comparison is known as a hazard quotient (HQ) and is given by the equation below:

$$HQ = \frac{\text{Estimated Dose (mg/kg-day)}}{\text{RfD (mg/kg-day)}} \quad \text{Equation 1}$$

Noncancer effects from exposure to multiple chemicals is evaluated by summing the hazard quotients to calculate a *hazard index*. This approach attempts to account for chemical interactions

and is discussed further on page 24.

Evaluating Cancer Risk

Some chemicals have the ability to cause cancer. Cancer risk is estimated by calculating a dose similar to that described above and multiplying it by a cancer potency factor, also known as the cancer slope factor. Some cancer potency factors are derived from human population data. Others are derived from laboratory animal studies involving doses much higher than are encountered in the environment. Use of animal data requires extrapolation of the cancer potency obtained from these high dose studies down to real-world exposures. This process involves much uncertainty.

Cancer Risk

Cancer risk estimates do not reach zero, no matter how low the level of exposure to a carcinogen. Terms used to describe this risk are defined below as the number of excess cancers expected in a lifetime:

<u>Term</u>		<u># of Excess Cancers</u>
moderate	is approximately equal to	1 in 1,000
low	is approximately equal to	1 in 10,000
very low	is approximately equal to	1 in 100,000
slight	is approximately equal to	1 in 1,000,000

Current regulatory practice suggests that there is no “safe dose” of a carcinogen and that a very small dose of a carcinogen will give a very small cancer risk. Cancer risk estimates are, therefore, not yes/no answers but measures of chance (probability). Such measures, however uncertain, are useful in determining the magnitude of a cancer threat because any level of a carcinogenic contaminant carries an associated risk. The validity of the “no safe dose” assumption for all cancer-causing chemicals is not clear. Some evidence suggests that certain chemicals considered to be carcinogenic must exceed a threshold of tolerance before initiating cancer. For such chemicals, risk estimates are not appropriate. More recent guidelines on cancer risk from EPA reflect the potential that thresholds for some carcinogenesis exist. However EPA still assumes no threshold unless sufficient data indicate otherwise.¹⁸

This document describes cancer risk that is attributable to site-related contaminants in qualitative terms like low, very low, slight and no significant increase in cancer risk. These terms can be better understood by considering the population size required for such an estimate to result in a single cancer case. For example, a low increase in cancer risk indicates an estimate in the range of one cancer case per ten thousand persons exposed over a lifetime. A very low estimate might result in one cancer case per several tens of thousands exposed over a lifetime and a slight estimate would require an exposed population of several hundreds of thousands to result in a single case. DOH considers cancer risk to be not significant when the estimate results in less than one cancer per one million exposed over a lifetime. The reader should note that these estimates are for excess cancers that might result in addition to those normally expected in an unexposed population.

Cancer is a common illness and its occurrence in a population increases with age. Depending on the type of cancer, a population with no known environmental exposure could be expected to have a substantial number of cancer cases. There are many different forms of cancer that result from a variety of causes; not all are fatal. Approximately 1/4 to 1/3 of people living in the United States will develop cancer at some point in their lives.¹⁹

Multiple Exposure and Toxicological Mixtures

A person can be exposed by more than one pathway and to more than one chemical. Exposure to multiple pathways occurs if a contaminant is present in more than one medium (i.e., air, soil, surface water, groundwater, and sediment). For example, the dose of a contaminant received from fish consumption may be combined with the dose received from contact with that same contaminant in sediment.

It is much more difficult, however, to assess exposure to multiple chemicals. In almost every situation of environmental exposure, there are multiple contaminants to consider. The potential exists for these chemicals to interact in the body and increase or decrease the potential for adverse health effects. The vast number of chemicals in the environment make it impossible to measure all the possible interactions between these chemicals. Individual cancer risk estimates can be added because they are measures of probability. When one is estimating noncancer risk, however, similarities must exist between the chemicals if the doses are to be added. Groups of chemicals that have similar toxic effects can be added, as in the case of volatile organic compounds (VOCs), which cause liver toxicity. Polycyclic aromatic hydrocarbons (PAHs) are another group of chemicals that can be assessed as one added dose based on similarities in chemical structure and metabolites. In the case of the LDW, PCBs and mercury have similar developmental effects. Although some chemicals can interact to cause a toxic effect that is greater than the added effect, there is little evidence demonstrating such synergy at concentrations commonly found in the environment.

There were hundreds of different contaminants reported in the data sets for fish/shellfish tissue and sediments from the LDW. Most of these contaminants were screened out because they were not at levels that caused health concern, or they lacked comparison values or quantitative toxicological information with which decisions can be made. For the purpose of this health assessment, the consideration and evaluation of the seven contaminants of concern in fish/shellfish and sediments were developed with assumptions that would be protective of human health.

ATSDR's interaction profile for persistent chemicals found in fish looked specifically at the interaction between polychlorinated biphenyls (PCBs), methylmercury, p',p'-DDE, chlorinated dibenzo-p-dioxins (CDDs), and hexachlorobenzene.²⁰ The profile concluded that data were inadequate to permit a determination of whether these compounds act independently of one another or in unison with regard to similar toxicological effects. Therefore, it was recommended that additivity be assumed as a public health protective measure in exposure-based assessments of the health hazards associated with exposure to mixtures of these components. In this health assessment, PCBs, mercury, and DDE were identified as contaminants of concern in LDW fish. The additive developmental hazards for these chemicals are considered, and as a result, consumption messages to women/pregnant women are emphasized.

The following evaluations do not rely solely on whether the estimated dose of a contaminant exceeds its health comparison value (i.e., MRL, RfD, cancer risk levels). Factors such as background exposure, a growing scientific data base, and the inherent uncertainty in assessing health risk are considered when formulating conclusions. These evaluations are based on current

data and subject to change should more data become available relative to the site and/or the toxic potential of the contaminants.

Uncertainty

Assessment of risks attributable to environmental exposures is filled with many uncertainties. Uncertainty with regard to the health assessment process refers to the lack of knowledge about factors such as chemical toxicity, human variability, human behavior patterns, and chemical concentrations in the environment. Uncertainty can be reduced through further study.

The majority of uncertainty comes from our knowledge of chemical toxicity. For most chemicals, there is little knowledge of the actual health impacts that can occur in humans from environmental exposures unless epidemiological or clinical evidence exists. As a result, toxicological experiments are performed on animals. These animals are exposed to chemicals at much higher levels than are found in the environment. The critical doses in animal studies are often extrapolated to “real world” exposures for use in human health risk assessments. In order to be protective of human health, uncertainty factors are used to lower that dose in consideration of variability in sensitivity between animals and humans, and the variability within humans. These uncertainty factors can account for a difference of two to three orders of magnitude in the calculation of risk. Furthermore, there are hundreds of chemicals for which little toxicological information is available for either animals or humans. These chemicals may in fact be toxic at some level, but risks to humans cannot be quantified because of uncertainty.

The amount of contaminated media (fish, soil, water, air) that people eat, drink, inhale, or absorb through their skin is another source of uncertainty. Although recent work has improved our understanding of these exposure factors, they are still a source of uncertainty. In the case of the LDW, uncertainty exists with respect to how much fish from the LDW people eat, how often they are eating it, what species they are eating, how often children use public access areas, or how much sediment or soil children may inadvertently eat. Estimates are based on the best available information or worst-case scenarios.

Finally, the amount and type of chemical in contaminated media is another source of uncertainty. Environmental samples are very costly, so that it is not practical or efficient to analyze an adequate number of samples for every existing chemical. Instead, sampling usually focuses on contaminants that are thought to be present according to historic land use or knowledge of specific chemical spills. In the case of the LDW, there are over 1,000 sediment samples that were analyzed for numerous chemicals. Most of the sediment samples were analyzed for PCBs because of knowledge of past industrial use; yet, there were several relevant chemicals, such as dioxin, for which very little was known. Furthermore, PCB congener data is also lacking for both fish and sediment, and arsenic species (inorganic vs organic) in fish are unknown.

Table 5. Completed Exposure Pathways in the Lower Duwamish Waterway

Pathway	Time	Source	Media and Transport	Point of Exposure	Route of Exposure	Exposed Population
Fish Consumption— Salmon	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Salmon	River	Ingestion	Recreational, subsistence, and general consumers
Fish Consumption— Pelagic Fish	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition	Pelagic Fish	River	Ingestion	Recreational and subsistence consumers
Fish Consumption— Bottomfish	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Bottomfish	River	Ingestion	Recreational and subsistence consumers
Contact with Sediments— Recreational/Workers	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Intertidal sediments	Parks and shoreline access points on the river	Incidental ingestion and dermal contact	Recreational beach users, habitat restoration, on-site workers, remedial workers
Contact with Sediments— Tribal netting	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Subtidal and intertidal sediments	River when nets are set for harvest of salmon	Incidental ingestion and dermal contact	Tribal fisherman
Contact with Sediments— Crab Fishing	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Subtidal and intertidal sediments	River when pots are set for harvest of crab	Incidental ingestion and dermal contact	Recreational crab fisher

Table 6. Potential Exposure Pathways in the Lower Duwamish Waterway

Pathway	Time	Source	Media and Transport	Point of Exposure	Route of Exposure	Exposed Population
Shellfish/Crab—Consumption	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Shellfish	River	Ingestion	Recreational and subsistence consumers
Contact with Sediments—Shellfishing	Past, Present, Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Intertidal sediments	River sediments	Incidental ingestion and dermal contact	Recreational and subsistence Shellfishers
Contact with Surface Water—Swimming	Past, Present Future	Industrial facility discharges and spills, municipal discharges, atmospheric deposition,	Duwamish river water column	Duwamish river study area	Incidental ingestion and dermal contact	Recreational river users

B. Completed Exposure Pathways

People who recreate or work along the Duwamish River can be exposed to contaminants in sediment and fish/shellfish. The following pathways analysis estimates exposure that might result from eating fish and contacting sediments in the LDW under various scenarios. Exposure assumptions and estimated doses are given in Appendix C.

1. Fish Consumption

Average and high-end exposure doses associated with fish consumption from the LDW were calculated for the contaminants of concern in various fish species. Fish consumption rates for various species commonly found in the LDW were taken from a recent survey of the Suquamish Tribe, using data gathered from fish consumers only, and from a study of recreational anglers in urban embayments of Puget Sound.^{21, 22, 23} Mean recreational consumption was used to approximate average fish consumption for LDW finfish. These rates were derived from a study of on-shore and boat anglers in urban embayments of Puget Sound. Crab and shellfish consumption was not reported in the recreational study; therefore, the median consumption rate from the Suquamish study was used to approximate average consumption for these species. Use of the recreational ingestion rates and median rate from the Suquamish study to predict exposure for an average fish consumer may be an overestimate.^a High-end consumption was taken from the 90th percentile values from the Suquamish. While there is no existing study of Muckleshoot fish consumption rates, the assumption that Suquamish tribal members eat a similar amount of fish as do the Muckleshoot is considered reasonable. The Suquamish survey reported the highest average consumption rate to date in Washington State. Exposure assumptions and estimated doses are given in Appendix C.

Exposure doses associated with consumption of groups of fish (anadromous, pelagic, benthic, and shellfish) were also calculated for average and high-end consumers. The recreational study did not present consumption rates for groups of fish. The Suquamish study did; therefore, median consumption rates from the Suquamish study were used to approximate the average consumer's exposure, and the 90th percentile consumption rate approximated high-end consumption. In addition to the median and high-end ingestion rates taken from the Suquamish survey, doses were calculated for Asian Pacific Islander (API) consumers by use of consumption rates from the Asian and Pacific Islander Seafood Consumption Study in King County.²⁴

One important aspect to consider when estimating exposure to contaminants in fish from a specific water body is the percentage of fish consumed from that water body relative to total fish consumption. If consumption of a particular species caught in the LDW is only a portion of the total amount consumed, then the overall dose for that species must consider the dose contribution from other fishing locations. For the purposes of this health assessment, it was assumed that

a - consumption rates from the recreational study (Landolt et al) were reported as g/day during the fishing season. This consumption rate was converted to g/kg/day assuming a body weight of 72 kg and the presence of fish in the fishery for 183 days per year for resident fish and 120 days per year for salmon. The resulting consumption rate may be biased high. Furthermore, the median ingestion rate from Suquamish fish consumers is likely to overestimate average consumption because Suquamish tribe ingestion rates are among the highest in Washington State.

individuals could rely on the LDW for their entire catch. With respect to salmon, this point is less important because little difference exists between contaminant levels in salmon caught from the LDW and contaminant levels in other areas of Puget Sound (see Table 7). This fact indicates that the relatively short residence time of immature salmon in the Duwamish River does not significantly contribute to the overall contaminant burden accrued over the life of an individual salmon.

Anadromous (Chinook and Coho Salmon)

Salmon caught in the LDW are consumed by recreational fishers and are an important resource for the Muckleshoot and Suquamish Tribes. Although salmon are a migratory fish and chemical concentrations in salmon are not thought to be site-related, there is a considerable amount of harvest and consumption of salmon from within the LDW study area. Therefore, chinook and coho salmon were evaluated in this public health assessment in order to determine the potential health risk to consumers of these species.

From 1992–1998, chinook and coho salmon were sampled within the LDW site and analyzed for pesticides, PCBs, arsenic, lead, copper, and mercury.²⁵

As shown in Table C3, doses calculated using average exposure assumptions do not exceed any respective RfDs. This result suggests that people who eat what is considered to be an average amount of coho and chinook salmon would not experience any noncancer adverse health effects. For the purpose of calculating the added effect of each contaminant of concern, a combined dose was compared to a “combined” RfD, called a *hazard index*. Combining all contaminant doses may overestimate the risk for noncancer health effects, but PCBs, DDE, and methylmercury are all associated with developmental and immune toxicity; therefore, it is appropriate to add the hazard quotients for these three contaminants.

The dose estimated for the average consumer of *all salmon types* (Table C6) exceeds the hazard index, but only slightly. Because the estimated doses for each individual contaminant are so far below the actual toxic effect levels upon which the respective RfDs are based, *the average consumer of salmon from the LDW is not expected to be at risk for any noncancer adverse health effects*.

High-end exposure doses estimated for both chinook and coho salmon consumption exceed the PCB RfD.^b The high-end consumption dose calculated for all salmon types is 5.4 times higher

RfDs and MRLs

Oral reference doses (RfDs) and minimal risk levels (MRLs) are levels of exposure to chemicals below which noncancer effects are not expected. MRLs are set by ATSDR for acute, intermediate, and chronic exposure. EPA sets RfDs based on chronic exposure only. An MRL or RfD is derived by dividing a LOAEL or NOAEL by “safety factors” to account for uncertainty and provide added health protection.

b- EPA provides an oral reference dose (RfD) for PCBs that is equivalent to and based on the same human exposure study as the MRL. RfDs have essentially the same definition as MRLs, but the two are not always equivalent. ATSDR recently completed an update of the PCB chronic MRL and did not change it. The agency did, however,

than the PCB RfD and 1.9 times higher than the RfD for methylmercury. These doses are still well below actual toxic effect levels. The background comparison given below in Section F, Table 7 indicates that salmon caught from the LDW study area do not have higher levels of contamination than salmon caught from more pristine areas of Puget Sound. DOH is currently evaluating the potential human health impacts of PCBs in Puget Sound fish.

The primary health concern associated with PCBs and methylmercury relates to developmental effects in children exposed in the womb. Immune system effects are also of concern for PCB exposure; they represent the toxic endpoint upon which the RfD and MRL are currently based. Cancer risks are evaluated below on page 33. Chemical-specific toxicity discussions for each contaminant of concern in fish are provided beginning on page 39.

Bottomfish (English Sole)

Concentrations of contaminants in English sole were selected as representative of bottom-dwelling fish. Consumption rates are available for English sole/flounder from the Suquamish Tribe survey. English sole contains relatively high levels of PCBs compared to other species. English sole are one of the most characterized and abundant species within the LDW.²⁶ English sole has not been reported as a harvested species in the Duwamish River, but outreach efforts indicate that flounder are caught in the river and may be confused with English sole.

The PCB dose estimated for the average consumer of English sole slightly exceeds the RfD. The recreational consumption rate used to calculate this dose may be an over-estimate because of the manner in which the data were presented.^c Average consumption of grouped bottomfish based on the median Suquamish consumption rate, on the other hand, does not exceed the hazard index (Table C6). Therefore, the average consumer who eats English Sole or bottomfish from the LDW is not expected to experience adverse health effects.

The high-end exposure dose for English sole, however, exceeds the PCB RfD by approximately 3-fold, and the dose for grouped bottomfish exceeds the PCB RfD by more than 6 times. The arsenic RfD was also exceeded in the high-end consumption of grouped bottomfish scenario.

The average level of PCBs in whole fish samples of English sole (958 ug/kg) is nearly 4-fold higher than for skinless fillets (267 ug/kg), while livers contain approximately 22-fold more PCBs (5828 ug/kg) than skinless fillets. Although sampling of whole fish and livers from English sole in the LDW is limited, data from other locations in Puget Sound support this indication that liver and whole body consumption will result in higher PCB exposure than consumption of skinless fillets (PSAMP).

provide a new intermediate MRL for exposure occurring during pregnancy. The intermediate MRL (0.00003 mg/kg/day) is only slightly higher than the chronic MRL of 0.00002 mg/kg/day.

c-Ingestion rates were reported as grams per day per season. Because seasons vary, it was unclear what an ingestion rate was over an entire year. For English sole in the LDW, it was assumed that a fishing season was 6 months because sole seasonally migrate to deeper water.

Other Finfish (Striped Perch and Quillback Rockfish)

Contaminants found in striped perch were chosen as representative of pelagic fish. There were no other species of pelagic fish sampled from the LDW.

Doses estimated for average consumers of perch exceed the hazard index, while doses for the high-end consumers do not. This anomaly is attributable to the fact that the consumption rate used to calculate an average person's exposure to perch was based on the consumption by shore anglers instead of the median consumption rate from the Suquamish study. The fact that high-end consumers from the Suquamish study eat substantially less perch than anglers may be indicative that the shore angler consumption rate is not representative of an average consumer.

The estimated dose for a high-end consumer of all pelagic fish, using contaminant concentrations in perch as a surrogate, exceeds the hazard index. PCB exposure contributes to the majority of the hazard index, with a calculated dose that is nearly three times higher than the RfD.

Although quillback rockfish are less well characterized, they are an important species to evaluate because of the elevated levels of PCBs and mercury detected in the limited sampling data that are available. It should be noted that the rockfish data assessed here come from samples taken from Elliot Bay near Harbor Island, which is adjacent to and north of the LDW study area. No rockfish samples are available from the Duwamish River, and it is not clear whether rockfish even exist in the river.

As indicated in Table C3 (in Appendix C), rockfish represent the most significant risk for fish consumers. The PCB dose calculated by use of average exposure assumptions is approximately double the RfD, while the high-end dose is 12-fold higher. In addition to PCBs, mercury levels are elevated in rockfish. The high-end dose for mercury triples the RfD. Data for the other contaminants of concern are not available for rockfish, an indication that overall risk could be underestimated. Although the rockfish data come from nearby Harbor Island samples, it is not certain if rockfish are present in the LDW. This assessment has included an evaluation of rockfish because of their high contaminant levels and their proximity to the LDW site.

While English sole and quillback rockfish represent the highest risk for consumers of finfish, it should be noted that the three whole fish samples of shiner perch contained an average of 496 ug/kg PCBs. Information from the WDFW indicates that shiner perch are harvested in the LDW¹². Data regarding PCB levels in shiner perch fillets were not located.

Total Finfish

The consumption rates used to evaluate exposure to contaminants in individual and groups of fish may underestimate total exposure by not accounting for the fact that people eat a variety of fish across groups. The Suquamish fish consumption study reported consumption rates for total finfish. However, many of the species included in that rate do not exist in the LDW. Therefore, the overall finfish consumption rate was not considered appropriate for exposure estimation. The dose estimates given above for individual species and groups are considered to be

sufficiently protective because consumption rates are based on consumers only, and they assume that 100% of an individual's fish diet could come from the LDW.

Crab

Crab were evaluated in this assessment because they are reportedly harvested in the LDW study area. A recent survey conducted by King County noted that while most respondents harvest crabs in the Elliot Bay/Harbor Island area, a few did report crabbing in the LDW. Edible meat samples from three individual dungeness and nine composite (45 total) red rock crabs taken from the LDW between 1996–1998 were analyzed for various contaminants.

Doses estimated from consumption of red rock crab do not exceed respective RfDs for the average or high-end consumer (Table C3). Average consumption of Dungeness crab also does not exceed RfDs; however, the high-end exposure dose calculated for Dungeness crab exceeds the PCB RfD by almost 4-fold and the arsenic RfD by 2-fold.

The sample size for Dungeness crabs is very small, so that there is not much confidence in the contaminant levels for these crabs. Red rock crabs, however, were sampled in greater number, and they too indicated elevated levels of PCBs and mercury. Therefore, it can be assumed that PCBs and mercury are elevated in both red rock and Dungeness crabs.

Other factors to consider are that arsenic dose calculations assume that 10 percent of the total arsenic value is the more toxic inorganic form. Because the percent of inorganic arsenic varies between species and can only be estimated, uncertainty is introduced into the arsenic dose estimates. Secondly, the Suquamish fish consumption survey indicates that, in general, adults eat more fish than children per body weight. However, consumption of Dungeness crab among children appeared to be higher per body weight than for adults, although sample size for children in this survey was small. Third, consumption rates for crab could be higher than estimated by the Suquamish survey as a result of the lack of other species (i.e., shellfish) available for harvest. In other words, subsistence consumers may collect more of one species if others are not available. The average consumption rate for all shellfish from the Suquamish survey (consumers only) is 10-fold higher than the rate for Dungeness crab or red rock crab alone.

Finally, a single hepatopancreas sample from a Dungeness crab showed 1647 ug/kg PCBs, more than 10-fold higher than average levels found in muscle tissue (130 ug/kg). While Dungeness crabs have not been adequately characterized in the LDW, sampling of the hepatopancreas in crabs harvested in Elliot Bay and other areas outside the LDW also indicates that this organ contains substantially higher levels of PCBs than muscle tissue. Samples from Elliot Bay revealed that PCB levels in the hepatopancreas were on average 80 times higher than average levels found in muscle tissue.^{27, 28}

Asian and Pacific Islanders

The Asian and Pacific Islander (API) community has been identified as a population that consumes fish from the LDW. In general, grouped fish consumption rates for APIs (90th percentile from API study) exceeded that of average fish consumers (median Suquamish rates),

but was less than that of high-end consumers (90th percentile Suquamish rates) for all groups except the pelagic group (Table C6). Estimated exposure doses exceed the hazard index for consumption of anadromous, pelagic, benthic, and shellfish fish groups (hazard indices of 2.4, 6.4, 5.3, and 3.7, respectively). Therefore, APIs are potentially exposed to contaminants in fish at levels of concern. In addition, the API Seafood Consumption Study revealed that a large percentage (>40%) of Asian Pacific Islanders surveyed consume the whole crab, including the hepatopancreas. Because of the tendency for contaminants to concentrate in the hepatopancreas, this population is therefore potentially exposed to higher levels of PCBs from crab consumption.

Cancer Risk—Fish Consumption

Cancer risks were calculated for fish consumers' exposure to COCs that potentially cause cancer in humans: arsenic, PCBs, chlordane, DDE, and seven different carcinogenic polycyclic aromatic hydrocarbons (cPAHs): benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, and chrysene. The PAHs were grouped together through use of toxic equivalency factors (TEFs). TEFs were applied to each individual PAH based on its relative toxicity to benzo(a)pyrene. The sum of TEF adjusted values is the toxic equivalent (TEQ).²⁹ Cancer risk estimates for exposure to individual species by use of average exposure assumptions range from slight (Red rock crab—1 cancer estimated per 1,000,000 exposed) to low (English sole—8 cancers estimated per 100,000 exposed. High-end exposure risk ranges from very low (perch—5 cancers estimated per 1,000,000 exposed) to low (English sole and rockfish—4 cancers estimated per 10,000 exposed).

In general, arsenic, cPAHs, and PCBs make up the bulk of the cancer risk from exposure to all species, with the highest cancer risks attributable to arsenic and cPAHs. cPAHs, however, were not detected in any finfish, but they were detected in some mussel samples. Finfish tend to metabolize PAHs more effectively than do shellfish, a fact that may explain why PAHs were found in mussels but not in finfish.³⁰ The methods used in the analyses of PAHs in finfish were not sensitive enough to make an accurate prediction of the amount of the contaminant in the fish. Although exposure to carcinogenic PAHs is expected to occur, the magnitude is likely to be considerably less than the estimated minimum background exposure from sources in food, water, air, and soil.

Risk associated with consumption of English sole was high compared to that of other finfish. Similarly, consumption of bottomfish, in general, represented the highest cancer risk compared to all groups of fish (Table C7). Consumption of Dungeness crab is associated with the highest cancer risk (Table C4). Most of this risk is attributable to arsenic, which is relatively high in Dungeness crab compared to most other fish species sampled. Cancer is the primary concern for adverse health effects associated with arsenic exposure. However, this concern is based on human exposure to inorganic arsenic in drinking water. It should be noted that important differences exist between exposure to arsenic in drinking water and exposure to arsenic in fish, including amount and type of arsenic absorbed.

Only slight risks are associated with exposure to DDE and chlordane in all species. A detailed discussion of chemical-specific toxicity is provided in this public health assessment, beginning on page 39.

2. Contact with Sediments

Humans come into contact with contaminated sediment in the LDW in a variety of ways. Tribal netfishers, crabfishers, and children playing along the shore are exposed to contaminants in the sediment through dermal contact and inadvertent sediment ingestion. These scenarios were used to conservatively calculate the dermal and ingestion exposure doses for each exposed population. Exposure assumptions used in the dose calculations are shown in Appendix C, Table C10.

Tribal Netfishing

The Muckleshoot Tribe harvests salmon from the LDW. In the course of doing so, sediment from the bottom of the LDW adheres to the nets, and tribal fishers who handle them come into contact with the sediment. Doses were calculated for tribal net fishers exposed to sediments through both dermal contact and inadvertent ingestion of sediment.

It was originally assumed that tribal net-fishing was conducted solely by adults; therefore, an exposure dose was calculated through use an adult netfisher scenario (exposure assumptions outlined in Appendix C, Table C10). The Suquamish Tribe indicated, however, that children frequently accompany family members while they are fishing and often grow to be fishers when they reach adulthood. A “worst case” exposure dose was therefore calculated on the basis of this information. All estimated doses were below RfD/MRLs, and the hazard index calculated for this scenario was well below one (Table C11). Therefore, *exposure to contaminants in sediment while net-fishing on the LDW is not likely to cause adverse noncarcinogenic health effects.*

Crab Fishers

Fish and Wildlife Enforcement officers have witnessed people catching Dungeness, red rock, and graceful crab near Terminal 105 and near the old railroad bridge near Harbor Island (see Figure 4).¹² Crab pots rest on the bottom of the LDW, and exposure to subtidal sediments is likely to occur when those pots are retrieved from the LDW. Crab fishing can also be accomplished by wading in intertidal areas and retrieving the crabs by hand or rake. Therefore, exposure to contaminants in intertidal and subtidal sediments is possible.

Crab fishing is thought to occur only at select locations; therefore, it is not appropriate to assume exposure to contaminant concentrations from the entire LDW. Sediment samples used to estimate exposure to crab fishers were selected from within a 1,000-foot radius of the Terminal 105 access point.

On the basis of exposure assumptions outlined in Appendix C, none of the estimated doses were found to exceed respective RfDs or MRLs. The hazard index is also less than one, indicating that *adverse noncancer health effects are not likely to occur as a result of direct contact with sediment during crab harvesting.*

Children Playing at Parks/Access Areas

At least 15 public access areas are along the LDW. Many of these access areas are boat launches and marinas, but there are a few places where children play, or might play. For the purpose of this health assessment, five access points were selected as probable locations where children can contact contaminated intertidal sediments: Duwamish Waterway Park, Gateway Park South, Gateway Park North, Boeing View Trail, and Herring's House Park (see Figure 4). Intertidal sediment samples from within 1,000 ft of each individual access area and on the same bank of the Duwamish were used to estimate exposure that occurs at each access point (Figures 5 and 6). Attempts to use samples from smaller radii to better evaluate exposure around each access point were made, but these radii yielded too few intertidal samples.

Estimated doses for children who play once per week at these locations were all below RfDs or MRLs. Furthermore, the highest hazard index was 0.4, associated with the Boeing View Trail site. Therefore, *no adverse noncancer health effects are expected to result from children playing at the parks along the LDW.*

Cancer Risk—Direct Contact

Cancer risks were calculated for direct contact exposure to COCs that potentially cause cancer in humans: arsenic, PCBs, DDE, chlordane, and seven different polycyclic aromatic hydrocarbons (PAHs): benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, and chrysene. The PAHs were grouped together by use of toxic equivalency factors (TEFs). TEFs were applied to each individual PAH according to its relative toxicity to benzo(a)pyrene. The sum of TEF adjusted values is the toxic equivalent (TEQ).²⁹ Chemical specific oral cancer potency factors were used in the calculation of cancer risks. Cancer risk estimates for each direct contact scenario are given in Appendix C, Table C12. Cancer risks are provided for each carcinogenic chemical and are also summed to yield an overall cancer risk.

Risk for netfishers was estimated based on a long-term exposure of an adult who net-fished on the LDW. The combined cancer risk for tribal fishers based on this scenario was low (approximately 9 cancers estimated for 1,000,000 persons exposed). The worst-case scenario of a child who accompanies an adult while fishing and then becomes a netfisher as an adult yielded a low cancer risk (approximately 1 cancer estimated for 100,000 persons exposed).

For assessment of cancer risks associated with people using LDW access areas, the exposure duration was carried forward from childhood to adolescence and into adulthood, for a total of 30 years. Combined cancer risks for five different access locations were calculated. Only very low cancer estimated risks were found. Risks ranged from a low of approximately 2 cancers estimated for 1,000,000 persons exposed (associated with the Duwamish River Park scenario) to a high of approximately 5 cancers estimated for 1,000,000 persons exposed (using the Boeing View Trail scenario).

Finally, cancer risks were estimated for a long-term exposure of an older child who crab-fishes on the LDW well into adulthood. The combined cancer risk for crab fishers based on this

scenario was very low (approximately 4 cancers estimated for 1,000,000 persons exposed).

Estimated cancer risks for all the preceding scenarios are very low. As mentioned previously, a lot of uncertainties are associated with estimating risk. Actual risks can be as high as those that are presented here, or they can be as low as zero (no risk). *The estimated cancer risks based on the exposure scenarios evaluated for direct contact with LDW sediments are not at levels of public health concern.*

Polychlorinated biphenyls—Toxic Equivalents (PCB-TEQs)

PCBs are a large family of similar chemicals called congeners. Some PCB congeners have been shown to cause toxic responses similar to those of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD or dioxin). Because TCDD is a potent carcinogen, the cancer risk associated with these dioxin-like PCB congeners should be evaluated. This is accomplished by adjusting dioxin-like PCB congener concentrations with toxic equivalency factors (TEFs) to account for the fact that they are less potent than TCDD.

TEFs have been derived for 12 dioxin-like PCB congeners, and those TEFs range from 0.1 to 0.00001.³¹ The concentration of a congener in a sample is adjusted by multiplying the laboratory result by the TEF to give a dioxin toxic equivalent (TEQ) for that congener. The sum of individual TEQs is known as the TCDD equivalent, which can be used with the TCDD cancer potency factor to estimate cancer risk.

Testing for PCBs

Different methods are used to detect PCBs in fish. The results presented as total PCBs are the sum of three different mixtures of PCBs called Aroclor-1248, -1254 and -1260, which are commonly found in fish. More specific analysis of individual PCB congeners can also be performed to provide a measure of dioxin toxic equivalents (TEQ).

Of the 1,200 sediment samples collected from the LDW, roughly half were analyzed for one or more PCB congeners. Less than a third of all analyses were above detection limits. PCB-126, the most potent PCB congener, was detected in only 16 of more than 600 samples analyzed. The high percentage of estimated and nondetected values, particularly with respect to congener PCB-126, indicates that a PCB-TEQ cancer risk calculation must be viewed with caution. For this reason, dioxin-like PCB risks are not presented with, or added to, cancer risks posed by other substances.

Fish tissue analyses did not include individual PCB congeners. The lack of PCB congener analysis in LDW fish could result in an underestimation of overall health risk to fish consumers because this lack represents a data gap.

C. Multiple Exposure Pathways

People who come into direct contact with LDW sediments are also likely to consume seafood from the LDW. This is especially true of tribal fishers. Combined exposure from the fish ingestion and direct contact pathways was assessed by use of the hazard index approach. The combined risk from both pathways is little different than the risk associated with fish consumption alone, indicating that direct contact with sediments contributes little to overall risk.

For example, the combined hazard index based on English sole consumption and sediment exposure for the tribal fisher scenario is 4.2, (4.1 HI for English sole consumption + 0.1 HI for sediment exposure = 4.2). Roughly 98% of the overall health risk in this example is attributable to English sole consumption.

D. Potential Exposure Pathways

Potential exposure pathways associated with the LDW site are discussed below. These pathways are not considered complete because data is lacking for key elements necessary for evaluation of exposure.

1. Shellfish Consumption

The DOH Food Safety and Shellfish Programs advise against consumption of shellfish harvested from the King County shoreline, except for Vashon-Maury Island (Figure 8). In addition, PH-SKC warns about contamination in shellfish, crab, and bottomfish near urban areas along the King County shoreline, including Elliott Bay and the Lower Duwamish Waterway. However, consumption of shellfish from the LDW study area has been reported among recreational and subsistence populations.

In an effort to determine the availability of shellfish from the LDW, two preliminary surveys were conducted, the first in June 2000 and the second in June 2001. According to these surveys, clams were located at each sampling site, but they were not thought to exist in high enough numbers to support recreational harvest. The survey also indicated that clams were relatively abundant between Kellogg Island (Figure 7) and Terminal 105 but that the site is accessible only by boat, a limitation on recreational harvest. Although the initial survey noted horse clams to be the most frequent species encountered, the following survey did not find any horse clams but did note an abundance of Eastern soft shell clams between Terminal 105 and Kellogg Island. It is likely that the initial survey mistook the soft shell for horse clams, because they are similar in appearance.³² EPA, NOAA, and the Muckleshoot Tribe reviewers found the surveys to be inadequate and, as a result, other surveys will be conducted in the future.

The Suquamish Tribe has expressed interest in the potential for future shellfish harvest in the LDW should there be a time when shellfish exist in adequate numbers. The Suquamish expressed concerns that current assessments and future cleanup efforts will not take into account the potential for a significant shellfish harvest by the tribe in the future.

Most of the contaminants of concern in fish and shellfish have been detected in mussels taken from the LDW. The data indicate that contaminant concentrations in mussels are generally lower than in other fish species; however, cPAHs were detected only in mussels. Estimated doses of contaminants from mussel consumption do not exceed any reference dose. Consumption of mussels from the LDW does not pose a significant risk of exposure to chemical contaminants. As noted previously, DOH advises against consuming shellfish from the LDW because of general pollution concerns that include sewage discharge.

No contaminant data for other shellfish species were located, a fact that can be considered a data

gap because different types of shellfish can accumulate varying amounts of contaminants.³³

2. Contact with Sediments—Shellfish Harvesting/workers

Individuals involved in recreational or subsistence harvest of shellfish may be exposed to contaminated intertidal sediments within the LDW site. Figure 4 provides an illustration of potential exposure points along the LDW site. Harvesting shellfish can result in exposure through inadvertent ingestion and dermal contact with contaminated intertidal sediments.

The extent of intertidal sediment sampling within the LDW varies considerably. Certain areas have been sampled extensively, while others are not well characterized. Few intertidal sediment samples have been collected between Kellogg Island and slip #4, and there are a number of public access sites located within this stretch of the LDW. Intertidal sediment where shellfish harvesters or on-site workers could contact contaminated sediments is limited.

Kellogg Island was chosen as a location where people can potentially catch shellfish because they were reported to be relatively abundant in that area. Sediment samples from the intertidal areas surrounding Kellogg Island were used to approximate the levels of contaminated sediment that a shellfisher would encounter. Estimated doses calculated for a 30-year exposure of an older child harvesting to adulthood did not exceed RfDs or MRLs. The hazard index was also less than one, indicating that *noncarcinogenic adverse health effects are not likely to occur as a result of direct sediment contact by people who shellfish near Kellogg Island.*

Cancer risk estimates for each of the contaminants of concern are given in Table C12. The cancer risk for shellfishers based on this scenario is very low (approximately 3 cancers estimated per 1,000,000 exposed people).

3. Contact with Surface Water—Swimming

Individuals engaging in water-related recreational activities such as swimming within the LDW may come into contact with contaminated surface water. Swimming in the LDW represents a potential exposure pathway of concern because this activity may result in incidental ingestion of and direct contact with contaminants in surface water. Estimating the amount of chemical exposure from swimming in the river is complicated by the lack of surface water sampling data and by the difficulty in estimating dermal absorption and other exposure parameters. Swimming within the LDW study area may also allow for the opportunity to come into contact with potentially contaminated intertidal sediments. However, exposure from swimming or other activities that result in contact with surface water is likely to be far less than that associated with consuming fish/shellfish.

Over 100 storm drains, a number of combined sewer overflows, and miscellaneous outfalls are within the LDW study area. CSOs along the LDW represent a potential concern for recreational swimmers (particularly during and following heavy rain events) because the CSOs discharge untreated sewage into the LDW during storm events when capacity is exceeded.

Sewage discharged by CSOs can introduce pathogens such as bacteria, viruses, helminthes, and

protozoa into the LDW water column.³⁴ Advisories warning against swimming near CSOs are posted along the King County shoreline and are discussed further on page 47.

The King County Water Quality Assessment evaluated recreational exposure to contaminants in LDW water. The assessment concluded that there was little risk associated with exposure to chemical contaminants in the water column. Pathogen levels, however, were frequently above levels considered acceptable for recreational purposes such as swimming or SCUBA diving.³⁴

E. Chemical Specific Toxicity

Arsenic

Arsenic occurs naturally in rock, soil, water, air, and plants. It can be distributed and concentrated in the environment through natural processes such as volcanic action, erosion of rock, or human activities. It is important to distinguish between organic and inorganic arsenic, because the inorganic form is more toxic. Natural mineral deposits in certain areas of Washington State contain large quantities of arsenic that can impact groundwater. In addition, arsenic is used in the production of wood preservatives and agricultural chemicals, including insecticides and herbicides. The production of glass and alloys involves the use of arsenic, and there are applications of its use in the electronics industry. Soil arsenic levels in the Puget Sound region have been affected by deposition from the ASARCO smelter that operated for nearly a century in Ruston, WA, until it closed in 1985.³⁵

Ingestion of inorganic arsenic has been reported to cause more than 30 different adverse health effects in humans, including cardiovascular disease, diabetes mellitus, skin changes, damage to the nervous system, and various forms of cancer. Numerous epidemiologic (human) studies of large numbers of people in several areas of the world have found strong associations between arsenic exposure in drinking water and cancer of the lung, bladder, and skin. The only large-scale study of the effects of arsenic-contaminated drinking water on a US population did not demonstrate an association between ingestion of inorganic arsenic in drinking water and cancer, although hypertensive heart disease appeared elevated in the exposed group.³⁶ The failure to detect an association with cancer in this US population could be explained by differences in exposure, population sensitivity, and statistical power.

EPA has established a chronic oral RfD for arsenic of 0.0003 mg/kg/day based on a NOAEL of 0.0008 mg/kg/day derived from a study in which a Taiwanese population was exposed to arsenic in drinking water.³⁷ Adverse health effects observed at or near the chronic LOAEL for this study of (0.014 mg/kg/day) include skin cancer, noncancer changes in the skin, vascular disease, and liver enlargement. Less serious effects were also observed in humans near this LOAEL of 0.014 mg/kg/day, including gastrointestinal irritation as evidenced by nausea, vomiting, and diarrhea.

EPA has classified arsenic as a known human carcinogen (Group A) and developed an oral cancer slope factor of 1.5 mg/kg/day to estimate the risk of skin cancer resulting from arsenic exposure. Although this number has been questioned, a recent evaluation by EPA suggests that this number may give a good estimate of combined cancer risk (including bladder and lung) from arsenic in drinking water.

All the toxicological data for arsenic discussed above is considered to be very strong, because these data are based on human exposure and they have undergone significant review. These studies, in fact, form the basis for a reduction in the federal drinking water standard. They are, however, based on drinking water exposure, as opposed to direct contact with sediment and consumption of fish associated with the LDW. Estimating an arsenic dose from fish consumption is particularly problematic because results are reported as total arsenic, with no distinction between inorganic or organic forms. Inorganic arsenic is thought to be the most toxic, while organic forms are less toxic. Some forms of organic arsenic, however, may be more toxic than others, or they may be converted to inorganic arsenic in the body. Available data indicate that inorganic arsenic levels in fish/shellfish vary widely, between 0.1–41%. Recent shellfish sampling conducted by ATSDR on Marrowstone Island indicated a ten-fold difference in inorganic arsenic content between horse and native littleneck clams.^{38,39} This assessment assumes that of the total arsenic reported in fish samples, ten percent consists of inorganic arsenic, an assumption that is consistent with current EPA guidance.⁴⁰

Methylmercury

Mercury is a naturally occurring element in several different forms. The most important form of mercury related to exposure at the LDW site is methylmercury, found in fish. Methylmercury is formed from inorganic mercury by microorganisms that are present in the environment. It is methylmercury that accumulates in the food chain and represents a potential health concern for consumers of fish. Mercury analyses evaluated in this assessment represent total mercury as opposed to methylmercury. Dose calculations, however, do not attempt to fractionate the concentrations, because nearly all the total mercury found in fish is expected to be in the organic, methylmercury form.

Developmental effects, the primary concern regarding methylmercury exposure, have been demonstrated in both animal and human studies. Recent evidence from two separate studies shows impaired development of children whose mothers were exposed to methylmercury by eating fish and whale meat. Mercury levels measured in the hair of these mothers were correlated with decreased performance in motor and learning skills. A third study showed no impact on childhood development in children whose mothers were exposed to mercury in fish while pregnant. ATSDR used this latter study to derive a NOAEL of 0.0013 mg/kg/day, upon which a chronic oral MRL of 0.0003 mg/kg/day is based. EPA derived an oral RfD of 0.0001 mg/kg/day, based on one of the former studies in which developmental effects were found.⁴¹

DOH recently derived a tolerable daily intake (TDI) range for methylmercury of 0.000035 to 0.00008 mg/kg/day based, on impaired neurological development in children exposed *in utero*.⁴² The upper bound of this range is consistent with EPA's oral RfD. DOH also recently evaluated methylmercury exposure in fish-consuming populations. The report concludes that some Native American fish consumers are likely to exceed the TDI for methylmercury according to a detailed analysis of fish consumption rates. The report also states that such over-exposure to methylmercury needs to be reduced below the TDI through consumption of a variety of salmon species in order to limit the amount of chinook salmon consumed. Chinook contain the highest levels of methylmercury of all the salmon species analyzed.^{43,44}

Methylmercury is considered to be a Group C possible human carcinogen by EPA, based on limited evidence in animals and inadequate evidence in humans. No cancer potency factor is available from EPA with which to estimate cancer risk. The evidence of developmental toxicity following *in utero* exposure is, however, of primary concern because of the substantial human evidence that forms the basis for a very low RfD.

Polychlorinated biphenyls (PCBs)

PCBs are a group of human-made chlorinated organic chemicals that were first introduced into commercial use in 1929 as insulating fluids for electric transformers and capacitors. Other applications were soon developed, including their use in hydraulic fluids, paint additives, plasticizers, adhesives, and fire retardants. Production of PCBs in the United States stopped in 1977 following concerns over toxicity and persistence in the environment.^{45, 46}

PCBs have 209 structural variations, called congeners, that vary by the number and location of chlorine atoms on the base structure. PCBs are often identified by one of their trade names, Aroclor. Aroclors are various mixtures of congeners defined by a four-digit number. The first two digits represent the number of carbon atoms, while the second two digits provide the percent by weight of chlorination for the congeners in that mixture.^d In general, PCB persistence and toxicity increase with the degree of chlorination in the mixture.

Liver toxicity has been demonstrated in animals given high doses of PCBs.⁴⁷ Liver toxicity and developmental effects are also well documented in residents of Taiwan and Japan exposed to relatively high levels of PCBs through ingestion of contaminated rice oil. However, the association of these effects with PCB exposure is complicated by concurrent exposure to chlorinated dibenzofurans.⁴⁶

While the “rice oil” incidents in Taiwan and Japan provide good evidence of PCB toxicity in humans, recent studies demonstrate that developmental effects can occur at lower levels of PCB exposure. Deficits in neurobehavioral function in children exposed *in utero* represent the most compelling evidence that environmental exposure to PCBs has caused adverse health effects in humans. Studies of various human populations exposed to PCBs, primarily through the ingestion of fish, have demonstrated deficits in neurobehavioral function. Learning deficits were maintained in the children of one Lake Michigan fish-eating cohort through 11 years of age. Animal studies have also shown adverse effects on development following prenatal exposure of the fetus.⁴⁸

Thyroid dysfunction has also been associated with PCB exposure. Several *in vitro* and animal studies have shown a reduction in thyroid hormone (thyroxine) levels in response to PCB exposure.^{49, 50, 51} A study in rats exposed *in utero* to PCBs found hearing deficits concurrent with decreasing thyroxine levels.⁵² This finding suggests that interference with thyroxine levels could be a mechanism for the developmental effects associated with children exposed to PCBs prior to

^d Aroclor-1016 does not follow this naming convention.

birth. The potential for PCBs to disrupt hormone function, including the endocrine system, has been suggested as a mechanism for the reproductive effects of PCBs seen in animals. Some human epidemiological studies provide support for the reproductive toxicity of PCBs, including effects on menstrual cycles in women and male fertility.⁴⁶

ATSDR has recently reviewed its MRL, considering the more recent human developmental studies discussed above. This review concluded that immune system effects seen in monkeys still represent the most sensitive toxic endpoint of PCB exposure. Further, ATSDR concluded that the existing MRL based on this endpoint should not change and is protective of the developmental effects found in the more recent human epidemiological studies discussed above.⁴⁶ DOH is currently evaluating the available literature to determine the most appropriate health comparison value for PCB exposure.

While high-dose animal studies demonstrate that PCBs can cause liver tumors in rats, *evidence that PCBs can cause cancer in humans is conflicting*. Some studies have linked human exposure to organochlorines with breast cancer, while other studies have found no association. Other studies suggest a link between PCB exposure in humans and non-Hodgkin's lymphoma (NHL), on the basis of higher PCB blood serum levels in NHL patients versus controls. One recent analysis of a large cohort of workers exposed while manufacturing PCB-containing transformers showed no increase in mortality, despite high PCB blood serum levels. The previously mentioned rice oil-poisoning incident in Taiwan did not reveal elevations in cancer mortality. However, an examination of residents similarly exposed in Japan did show an increase in mortality from liver cancer.

As noted previously, some PCBs are thought to exert toxicity via a dioxin-like mechanism. Current evidence indicates that 12 PCB congeners act through this mechanism by virtue of a planar structure that allows for binding to the Ah receptor. For each of these, a toxic equivalency factor (TEF) has been established on the basis of enzyme activity triggered through the binding of this receptor. The amount of enzyme activity induced by each congener is compared with that of 2,3,7,8-tetachlorodibenzo-p-dioxin (TCDD) in order to generate each TEF. Congener concentrations are multiplied by their respective TEF to generate the dioxin toxic equivalent value. This value can then be used in conjunction with the cancer potency factor for TCDD to estimate a PCB-TEQ cancer risk.

Considerable uncertainty exists with this approach, but it does provide an important estimate of PCB toxicity that may be distinct in both mechanism and toxic endpoint. Some evidence suggests that the dioxin-like congeners correlate with immune system and fetal growth effects, but not with neurobehavioral impairment.^{53, 54, 55}

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are generated by the incomplete combustion of organic matter, including oil, wood, and coal. They are found in materials such as creosote, coal, coal tar, and used motor oil. Fifteen PAHs of similar structure and physical/chemical properties have been identified in significant quantities in the environment. On the basis of these similarities along with similarities in metabolism and toxicity, PAHs are often grouped together

when one is evaluating their potential for adverse health effects. Some of this group of PAHs have been classified as probable human carcinogens (Group B2) by EPA as a result of *sufficient* evidence of carcinogenicity in animals and *inadequate* evidence in humans.⁵⁶

Benzo(a)pyrene is the only PAH for which EPA has derived a cancer slope factor. That cancer slope factor was, therefore, used as surrogate to estimate the total cancer risk of PAHs in sediment. It should be noted that benzo(a)pyrene is considered the most carcinogenic of the PAHs, and use of its cancer slope factor as a surrogate for total PAH carcinogenicity may overestimate risk. To address this issue, DOH made an adjustment for each cancer-causing PAH based on the relative potency of that PAH to the potency of benzo(a)pyrene. Evidence of PAH carcinogenicity in humans and animals indicates that tumor location is relevant to exposure route, with dermal and inhalation doses yielding skin and lung tumors, respectively.

Fish and shellfish can accumulate PAHs, and uncooked fish typically contain some PAHs. Benzo(a)pyrene levels in shellfish from uncontaminated waters, for example, is estimated to be around 3 ppb. Detection limits used in the analyses of LDW fish and shellfish, however, were not adequate to distinguish the level of PAH contamination. Cooked meats further add to PAH exposure in the diet. Dietary sources make up a large percentage of PAH exposure in the US population, and smoked or barbecued meats and fish contain relatively high levels of PAHs. However, the majority of dietary exposure to PAHs for the average person comes from ingestion of vegetables and grains (cereals).⁵⁷

Cadmium

Cadmium, a metal that occurs naturally in the environment, is used mainly in batteries, pigments, metal coatings, and metal alloys.

The RfD for cadmium that is ingested with food is 0.001 mg/kg/day, based on adverse effects in the kidney. EPA classifies cadmium as a Group B1 probable human carcinogen based on limited evidence in human occupational settings and on sufficient evidence in animal studies. Occupational exposure to inhaled cadmium is suspected to be a cause of lung cancer in workers, while animal studies have confirmed the ability of cadmium to cause lung tumors via the inhalation route. Studies of workers exposed to airborne cadmium also suggest a link with prostate cancer. The ability of cadmium to cause cancer via the oral route is disputed. Several human population and laboratory animal studies have failed to show cadmium to be carcinogenic by the oral route, but other studies indicate an increase in prostate tumors, testicular tumors, and leukemia in rats following high dietary doses of cadmium.^{58,59}

Cadmium is found in most foods at low levels, with the lowest levels found in fruits and the highest found in leafy vegetables and potatoes. Shellfish have higher cadmium levels (up to 1 ppm) than other types of fish or meat.

p,p'-Dichlorodiphenyldichloroethylene (DDE)

DDE is a compound formed when the pesticide DDT breaks down in the environment. DDT was banned for use in the United States in 1972, but because of its persistent nature, DDT and its

degradation products are often found in fish and other food products.

Neither EPA nor ATSDR have established oral an RfD or an MRL for DDE, but EPA gives an RfD of 0.0005 mg/kg/day for DDT, based on increased liver size in rats exposed to commercial DDT in the diet. EPA classified DDE as a Group B2 probable human carcinogen based on sufficient evidence of carcinogenicity in animal studies and no data in humans. Dietary exposure to DDE caused liver tumors in two strains of mice and in hamsters, from which EPA derived an oral slope factor of 0.34 per mg/kg/day. Dietary exposure to DDE also caused thyroid tumors in female rats.

ATSDR's draft interaction profile recommends adding similar noncancer health effects associated with DDE and other contaminants in fish.

Chlordane

Chlordane is a pesticide that was banned in the United States in 1988. It, too, is very persistent in nature, and it is lipophylic, resulting in its accumulation in animal fat.

The RfD for chlordane is 0.0005 mg/kg/day, based on liver toxicity in male mice. EPA has classified chlordane as a Group B2 probable human carcinogen based on sufficient evidence of cancer in animals and inadequate data in humans. Exposure to chlordane produced liver tumors in five strains of mice, an experiment from which EPA derived an oral slope factor of 0.35 per mg/kg/day.

F. Comparison with Background

Table 7 below presents a comparison of contaminants found in Duwamish River fish to those found in fish from nonurban areas of Puget Sound.

Table 7. Comparison of contaminants in fish from the Duwamish River versus nonurban areas of Puget Sound ^{a, b, c, d, 23}

Contaminant	Chinook		Coho		English Sole		Rockfish	
	Duwamish	nonurban ^c Puget Sound	Duwamish	nonurban Puget Sound	Duwamish	nonurban Puget Sound	Elliot Bay (near Harbor Island)	All other locations in Puget Sound
Aroclor-1254	34	30	28	19	143	7.4	73	6.9
Aroclor-1260	20	21	11	11	68	7.6	219	4.6
Mercury	99	87	42	51	48	51	408	288
Arsenic	1.0	1.0	0.8	0.7	11	7.4	NA	2.4

a = Mean concentrations were used for this comparison, with nondetects included as whole value

b = Values are given as parts per billion (ppb) except for arsenic values, which are in parts per million (ppm)

c = Nonurban locations are Deschutes, Nisqually, Skagit, and Nooksack rivers

d = All data are from the Puget Sound Ambient Monitoring Program

This comparison clearly indicates that English sole in the Duwamish River have been impacted by a source of PCBs that is not universally affecting Puget Sound. Arsenic levels in English sole

from the LDW may be elevated in comparison with background. Also of note are the relatively high PCB levels in quillback rockfish samples from Elliot Bay near Harbor Island compared to background and to other species. Though it appears that Harbor Island rockfish have higher mercury levels than the rest of Puget Sound, this comparison cannot be made unless the data are age-adjusted. At any rate, these data indicate that limiting consumption of English sole from the LDW and quillback rockfish from Elliot Bay near Harbor Island will reduce overall exposure, even if consumption of other species is increased.

Chinook and coho salmon PCB levels in nonurban areas of Puget Sound are similar to those found in the LDW. The Washington State Department of Fish and Wildlife estimated that about 99% of PCBs in adult chinook salmon returning to spawn in the Duwamish/Green River watershed were accumulated in marine waters of Puget Sound or the Pacific Ocean. Furthermore, PCB levels in Coho are slightly lower in northern Puget Sound, and they gradually increase in southern areas of Puget Sound.⁶⁰ The reason for this trend is thought to be related to the residence time for Coho in Puget Sound. The longer a fish resides in Puget Sound, the more time it has to accumulate PCBs. Salmon returning to watersheds in southern Puget Sound must spend a longer time in the Sound, where exposure to PCBs is greater than in the open Pacific Ocean.

Fish from even the most pristine water bodies will accumulate some chemicals from either natural or wide-spreading anthropogenic sources. Reported average mercury levels for the top 10 types of fish consumed in the US range from 20–206 ppb. PCB levels detected in Washington freshwater fish fillets (excluding those in the Spokane River) range from 3.4–300 ppb (mean = 49).^{e,61} Therefore, subsistence consumers or other people who eat a lot of fish are potentially at risk of adverse health effects even if they eat fish relatively low in contaminants.

G. Benefits of Fish Consumption

It is important to consider the very real benefits of eating fish. Fish is an excellent source of protein, and it has been associated with reduced risk of coronary heart disease. The health benefits of eating fish have been associated with low levels of saturated versus unsaturated fats. Saturated fats are linked with increased cholesterol levels and risk of heart disease, while unsaturated fats (e.g., omega-3 polyunsaturated fatty acid) are an essential nutrient. Fish also provide a good source of some vitamins and minerals.^{62, 63} The American Heart Association recommends two servings of fish per week as part of a healthy diet.⁶⁴

The health benefits of eating fish deserve particular consideration when one is dealing with subsistence consuming populations. Removal of fish from the diet of subsistence consumers can have serious health, social, and economic consequences that must be considered in issuing fish advisories. The Muckleshoot rely on salmon harvested from the Duwamish River as part of a healthy diet, as a valuable income source, and as an important part of a rich cultural heritage. Other communities living near the Duwamish River may also be impacted by advisories that recommend limits on fish consumption. Outreach efforts indicate that some residents among API communities may eat higher quantities than estimated in this assessment. Consumption

^eBased on composite samples of freshwater species from several lakes/rivers (excluding the Spokane River). Nondetects eliminated from analysis because of high detection limits in some analyses.

advisories for these high-end consumers could, therefore, significantly impact diet.

Any advice given to fish consumers to reduce the amount of fish they eat based on chemical contamination should attempt to balance the health benefits with the health risks. In general, people should eat fish low in contaminants and high in omega-3 fatty acid. Table 8 below shows published levels of omega-3 fatty acid in fish species compared to the average levels of PCBs in LDW fish. Salmon (chinook and coho) have the highest levels of fatty acids and the lowest levels of PCBs; they therefore should be the preferred fish to eat from the LDW.

Table 8—Published levels of omega-3 fatty acid compared to PCB levels in LDW fish, Seattle, Washington⁶⁵

Fish Type	omega 3 fatty acid (mg/g) ^a	PCB levels in LDW fish (ug/g)
Chinook	14	51
Coho	8	36
Sole / Flounder	2	267
Perch	3	111
Crab	3	110

a = sum of Eicosapentanoic acid (EPA) and Docosohexaenoic acid (DHA)

Fish consumption advice should also take into account that eating alternative sources of protein also has risks. For instance, increasing the consumption rate of beef or pork at the expense of eating fish can increase the risk of heart disease. In addition, some contaminants that are common in fish, such as dioxin, might also be present in other meats.

Exposure to contaminants in fish can be significantly reduced through simple preparation measures. Simply removing the skin of the fish has been shown to reduce PCB exposure.⁶⁶ Samples of LDW striped perch with and without skin support the notion that removal of skin reduces contaminant levels. Skinless striped perch fillets from the LDW contained levels of PCBs that were nearly 30% lower than fillets with skin (Table 9). Furthermore, cooking fish also reduces PCB levels in the fillets by more than 20%, and in some cases, PCBs were nearly entirely removed through cooking.^{67, 68} Boiling seafood such as shellfish or crabs can reduce exposure to some contaminants, provided that the water is discarded and not incorporated into a broth.

Table 9. Comparison of PCB levels in striped perch fillets (skinless vs with skin fillets) from the Lower Duwamish Waterway located in Seattle, King County, Washington

Mean PCB levels in Striped Perch Samples from the Duwamish River (ppb)		
With Skin	Without Skin	Decrease
160	113	29%

H. Existing Advisories

PH-SKC has an existing fish consumption advisory for urban areas along the King County shoreline, including Elliott Bay and the Lower Duwamish Waterway. The advisory warns of contaminants in shellfish, crab, and bottomfish. DOH Food Safety and Shellfish Programs advise against eating shellfish from the King County shoreline, except for Vashon-Maury Island, on the basis of biological and chemical contamination associated with urban environments. Community outreach efforts, discussed above, have indicated that the communities surrounding the LDW site are mostly unaware of these advisories. The advisory from PH-SKC does not provide consumption limits, nor does it give specific advice against eating any of these species.

PH-SKC also advises against swimming near CSOs, of which there are many in the LDW. This advisory warns people of the “*dangers of swimming or fishing in water that might be polluted because of a sewer pipe overflowing in the area during and after heavy rain. Bacteria and chemicals from CSOs can increase the risk of getting sick from swallowing the water or eating the fish. Public Health recommends that people not go in the water near these signs for 48 hours after a heavy rain.*” More health-related information about CSOs is available from PH-SKC at <http://www.metrokc.gov/health/wasteh2o/csoindex.htm#fish>.

DOH has issued a statewide fish advisory recommending that women of child-bearing age and children under six years of age limit their consumption of canned tuna fish and not eat swordfish, shark, tilefish, king mackerel, or fresh-caught or frozen tuna steak. More information regarding this advisory is available at <http://www.doh.wa.gov/fish> or by calling toll-free 1-877-485-7316. DOH is currently evaluating PCB contamination in Puget Sound fish. If more stringent consumption limits are derived from this evaluation, they will be applicable to the Duwamish River.

I. Fish Meal Limits

The following meal limits in Table 10 were derived from average and high-end mercury and PCB levels in LDW fish/shellfish. Limits were calculated using average concentration estimates of mercury and PCBs for various fish species with a target hazard index of 1. Exposure parameters are provided in Appendix C, Table C8. These limits represent consumption rates that would be protective of people who consume fish from the LDW. While it is not likely for a person to eat fish solely from the LDW, the limits in Table 10 are for individual species harvested from the LDW. Depending on the source of the fish, people may be able to safely eat more fish meals than shown in Table 10.

The limits are calculated based on fillets or muscle tissue without skin. Consumption of whole fish at these meal limits may result in exposure above safe levels. On the contrary, proper preparation and cooking will reduce PCB exposure further below safe levels.

Table 10. Meal limits based on PCB, mercury, and DDE contamination in Lower Duwamish Waterway fish, Seattle, Washington.

Fish Species	Recommended 8 ounce meals per month	
	Developmental ^b	Immune ^c
English Sole	0.9	0.7
Perch	2.1	1.7
Chinook	3.0	3.7
Coho	5.0	5.2
Red Rock Crab	1.9	1.7
Rockfish ^a	0.6	0.6

a = Rockfish were sampled from Elliot Bay near Harbor Island

b = Based on developmental endpoint of PCBs, mercury, and DDE, assuming a female body weight of 60 kg

c = Based on the Immune endpoint of PCBs, assuming an adult body weight of 70 kg

Applying the Table 10 meal limits across the general population assumes that meal size will decrease proportionately with body weight. Such an assumption could result in an underestimate of exposure for consumers who eat proportionately more fish per unit of body weight. Table 11 demonstrates how an eight-ounce meal for a 70-kilogram adult would change to remain proportional with body weight.

Table 11. Adjustment of fish meal size based on the body weight of a fish consumer

Body Weight (lbs)	Adjusted Meal Size (oz)
200	10.4
150	7.8
100	5.2
50	2.6
25	1.3
20	1.0

It is important to consider that commercially purchased fish also have contaminants. People who abide by meal recommendations for LDW fish based on Table 10 but also eat commercially bought fish may increase their risk for adverse health effects.

J. Child Health Considerations

ATSDR recognizes that infants and children may be more vulnerable to exposures than adults when faced with contamination of air, water, soil, or food.⁶⁹ This vulnerability is a result of the following factors:

- Children are more likely to play outdoors and bring food into contaminated areas.
- Children are shorter, and their breathing zone is closer to the ground, resulting in a greater

likelihood to breathe dust, soil, and heavy vapors.

- Children are smaller and receive higher doses of chemical exposure per body weight.
- Children's developing body systems are more vulnerable to toxic exposures, especially during critical growth stages in which permanent damage may be incurred.

In this health assessment, exposure scenarios took into account the factors listed above. With regard to fish consumption, ingestion rates from the Suquamish study were normalized based on body weight. The use of adult consumption rates from the Suquamish study was considered to be protective of children as a result of the finding that Suquamish adults eat more fish per body weight than do children (with the exception of Dungeness crab). The sediment exposure scenarios at public access areas recognized children as the most sensitive receptor and the most likely to be exposed to contaminated sediments.

New draft guidance from EPA recognizes that early life exposures associated with some chemicals requires special consideration with regard to cancer risk.⁷⁰ Mutagenic chemicals, in particular, have been identified as causing higher cancer risks when exposure occurs early in life, compared to the same amount of exposure during adulthood. cPAHs have been identified as a mutagenic contaminant of concern in the LDW. Arsenic, DDE, and Chlordane have also tested positive on some assays used to determine a chemical's mutagenic potential. Adjustment factors have been established to compensate for higher risks from early life exposures to these chemicals. A factor of 10 is used to adjust early life exposures before age two, and a factor of 3 is used to adjust exposures between the ages of 2 and 15. The following example shows how the lifetime increased cancer risk from exposure to cPAHs from consumption of English sole would be adjusted to account for early life exposure.

Example:

The cancer risk attributed to cPAH exposure in high-end (subsistence) consumers of English sole is 5×10^{-5} resulting from a lifetime average daily cPAH dose of 7×10^{-6} mg/kg/day (Table C4). The adjusted risk is as follows:

$$7 \times 10^{-6} \text{ mg/kg/day} \times 7.3 \text{ kg-day/mg} \{ (2\text{yr}/70\text{yr} \times 10) + (13\text{yr}/70\text{yr} \times 3) + (55\text{yr}/70\text{yr}) \} \\ = 7 \times 10^{-6} \text{ mg/kg/day} \times 7.3 \times (114/70) = 8 \times 10^{-5}$$

The adjustment increases the overall risk associated with cPAH exposure from 5×10^{-5} to 8×10^{-5} , or a factor of less than 2. While it may be appropriate to adjust each of the cancer risks attributable to cPAHs by this factor, it should also be remembered that cPAHs were not detected in any finfish, and therefore the theoretical cancer risks are both very low and highly uncertain.

Community Health Concerns Evaluation

A number of community health concerns related to the LDW were expressed during community interviews and outreach activities. Specific individual health concerns identified during

community interviews and outreach activities are addressed individually below.

1. Are the salmon in the Duwamish River site safe to eat?

An evaluation of both chinook and coho salmon tissue data indicates that eating salmon caught from the river is no different from eating salmon caught from other areas of Puget Sound. Salmon are a migratory fish, and contaminants present in salmon tissue are assumed to have originated from sources outside the LDW study area. However, salmon were evaluated in this public health assessment because they are harvested commercially from the LDW and are consumed by recreational and subsistence populations.

This assessment indicates that people who eat large amounts of salmon caught in the LDW could have a small increased risk of adverse health effects. This risk would be of most concern for pregnant women or women considering pregnancy. However, this risk may be completely offset by the benefits of eating salmon, particularly for some consumers who may have poor nutritional alternatives to this resource. Because the contaminant levels in LDW salmon do not appear to be any different from the levels in other areas of Puget Sound, the issue of exposure through consumption of salmon must be dealt with across all of Puget Sound. PCBs are the primary contaminant of concern in salmon found in the LDW and across Puget Sound. DOH is currently evaluating PCB consumption of Puget Sound fish. This evaluation is being done separately from this health assessment.

2. Is seafood from markets safe to eat? How do we know? How is it regulated?

Washington residents should continue to eat fish as part of a healthy diet. The Washington State Department of Agriculture inspects seafood for wholesale processing. Its method is called the Hazard Analysis Critical Control Point plan. It applies to wholesalers, and ensuring safety regarding storage temperatures, species specifications, ingredients and potential allergens, and cross-contamination. It does not include testing for chemicals. Most wholesalers buy fish from reputable commercial fishers who do not harvest in the Duwamish River; however, anecdotal information obtained from a PH-SKC focus group with Vietnamese elders revealed that people may catch fish in the Duwamish and sell it to local markets. This report has not been verified. For more information, contact Jim Pressley at the Washington State Department of Agriculture at (360) 902-1860.

The Washington Department of Health (DOH) monitors shellfish growing areas. Shellfish harvesting is permitted only in areas with no past history of industrial uses. The Lower Duwamish Waterway is closed for commercial shellfish harvesting, as is the King County shoreline, except for Vashon-Maury Island. DOH conducts inspections of wholesalers of mollusk and shellfish. Shellfish are inspected for biotoxins, not chemical contaminants. These shellfish should be safe to eat if the grocer keeps them refrigerated and does not store them at room temperature.

Local health agencies are responsible for inspections at the markets. The local health agency does not test for chemicals but does rely on state certification tags for biotoxin safety, indicating that the product comes from an approved source. Public Health Seattle and King County (PH-SKC)

conducts inspections at markets four times per year. PH-SKC checks to see that seafood products sold in markets come from an approved source. If the seafood does not come from an approved source, the market receives a hold order, is expected to comply with voluntary removal, and signs a waiver to destroy the product. The market is not fined, and this process operates primarily on the honor system. For more information on local health inspection policies, contact Leonard Winchester of PH-SKC at (206) 296-9842.

The Food and Drug Administration (FDA) inspects samples from commercial fishing and packaging plants. The FDA also conducts the Market Basket Survey, through which food products from the grocery store are randomly inspected. Food products need to be shipped over state lines for the FDA to have jurisdiction; otherwise, the state is responsible for food safety inspections. For more information, contact Sue Hutchcroft at the FDA at (425) 483-4983.

All things considered, it would be wise to ask your local grocer where he/she buys a product. If he/she does not provide a satisfactory answer, you may want to do your shopping elsewhere.

3. Will it be safe to harvest seafood from the LDW site when it is cleaned up?

The potential for uptake and bio-accumulation of contaminants varies, depending on the type of fish/shellfish and the amount and type of contaminant. As the cleanup of the LDW site progresses, additional sampling will be conducted to verify that cleanup actions are effective. It should also be noted that a number of upland sources have been identified as potential sources of LDW contamination. These potential sources will be addressed by Ecology throughout the LDW site cleanup.

PCBs are the major contaminant of concern related to fish consumed from the LDW. While cleanup is expected to reduce PCB levels in both fish and sediment, it is likely to take many years before any appreciable decline is seen in fish. Measurable decreases in PCB levels are expected only for those fish species that are resident in the LDW.

4. When will the site be cleaned up?

The LDW is an enormous site (6 miles of river and shoreline area) and will require a number of years to clean up. The Environmental Protection Agency is the lead agency in terms of site cleanup activities. For specific questions regarding the time frame for cleanup or specific cleanup activities for the LDW site contact Allison Hiltner at EPA (206) 553-2140 or Ravi Sanga (206) 553-4092. Questions relating to upland source control activities should be directed to Rick Huey at Ecology at (425) 649-7256.

5. What species of fish/crab/shellfish are safe to eat (if any) in the river?

People who eat fish occasionally from the LDW are not likely to be exposed to chemical contaminants at levels of health concern. High-end (subsistence) consumption of fish from the river, however, is of concern. As a result, this health assessment has recommended meal limits for resident fish. Salmon from the LDW have contaminant levels similar to those in salmon in other areas of Puget Sound and have lower PCB levels than resident LDW fish.

6. Why are signs not posted at the river if there is a pollution problem?

DOH, PH-SKC, EPA, and Ecology are addressing this issue. There is an existing health advisory for urban areas along the King County shoreline, including Elliott Bay and the Lower Duwamish Waterway, but the advisory has not been well documented, communicated, or understood by potentially impacted populations. This health assessment recommends better communication of existing advisories (see page 58).

7. Is it safe for children to play in the sand along the river at the Duwamish River Park and the other little park along the river in South Park?

Yes. Childhood exposure to chemical contaminants associated with the LDW were evaluated at several public access areas (see page 35). There was very little risk to children playing at parks. It should be noted that the sediment near public access areas has not been well characterized, but worst-case exposure scenarios based on existing data did not reveal significant increases in health risk. Additional sampling is planned at public access areas in order to identify the potential need for cleanup. The new data gathered are not anticipated to significantly change the conclusion in this health assessment.

8. Is it safe to picnic at these parks?

Yes. See question 7

9. Is it safe for habitat restoration workers to work along the riverbanks? If not, what precautions should they take to reduce exposure (gear)?

Exposure to chemical contaminants in LDW sediment through direct contact does not appear to be a significant public health concern. However, items such as debris, glass, and unstable rock and riprap materials could represent a physical hazard for individuals involved in habitat restoration activities. Rubber gloves and boots would be appropriate attire to protect against physical hazards.

10. What are the “hot spots” along the river (particularly pertaining to marinas)?

EPA is currently in the process of identifying sediment “hot spots” along the LDW study area for early remedial action. Questions relating to sediment “hot spots” and early action activities should be directed to Allison Hilter at EPA at (206) 553-2140.

11. Is it safe to swim, wade, or to kayak in the river?

The King County Water Quality Assessment concluded that occasional swimming or recreation in the Duwamish River is not likely to result in chemical exposures of a health concern. However, combined sewage overflows may contribute pathogens and viruses to the river that are a concern for swimmers. PH-SKC has an existing advisory warning against swimming near combined sewer overflows, especially after periods of heavy rain when untreated sewage may be present.

12. How are contaminants evaluated?

This assessment evaluated environmental contamination in the LDW by using ATSDR guidance, guidance from state and other federal agencies including EPA and Ecology, and primary literature sources. A description of the process is given in the Environmental Contamination section (see page 17) and the Pathways Analysis/Public Health Implications section (see page 22). In the case of the LDW, primary exposure pathways involve consumption of contaminated seafood and direct contact with contaminated sediments.

13. Is the river causing respiratory problems?

Contaminants associated with the river are not of concern for respiratory problems. However, the LDW is situated in the heart of a highly industrialized area with a number of air emission sources. Major sources in the area include industry, automobiles, and airplanes, all of which can contribute to respiratory effects. Air emissions in this area are regulated by the Puget Sound Clean Air Agency. You can contact the Puget Sound Clean Air Agency at (206) 689-4040 or 1-800-552-3565, e-mail: commedu@psapca.org, URL: <http://www.pscleanair.org>.

14. What about aerial deposition from cement plants?

Aerial emissions from cement plants is regulated by the Puget Sound Clean Air Agency. You can contact the Puget Sound Clean Air Agency at (206) 689-4040 or 1-800-552-3565, e-mail: commedu@psapca.org, URL: <http://www.pscleanair.org>.

DOH is currently evaluating a cement plant located along the Duwamish River. For more information regarding this assessment, please contact Gary Palcisko toll-free at 877-485-7316 or 360-236-3377.

15. Are mortality rates higher for people exposed to contamination in the waterway?

In order to determine if mortality rates are higher for people exposed to LDW contamination, an exposed population needs to be identified and compared to an unexposed population. In the case of the LDW site, census tracts could be utilized in an effort to define the potentially exposed population. However, it would be unclear as to what extent the population within the defined area comprised the exposed or potentially exposed population. This fact represents a significant barrier when one is addressing the mortality rates in people exposed to LDW contamination. The state Board of Health reports that the communities of South Park and Georgetown have higher mortality rates and decreased life expectancies when compared to the City of Seattle as a whole. Though it has been theorized that the communities' proximity to heavy industry contributes to this trend, there are no studies in Washington State that confirm this theory.⁷¹

16. Is the water in the Duwamish site a source of drinking water?

DOH is not aware of anyone using the LDW as a source of drinking water. Drinking water is

provided by the City of Seattle to industry and residences in this area. The city of Seattle obtains the majority of its drinking water from the relatively pristine Cedar and Tolt River watersheds. Drinking water is routinely tested to ensure that it is safe for human consumption.

17. Is it safe for pets to have access to the waterway?

This PHA does not specifically address pet exposures. Evaluation of human exposure to contaminated water and sediments at public access areas indicates very little risk. PH-SKC does advise humans not to swim in the river after heavy rain because of possible raw sewage discharge.

18. Is the water from the Duwamish a health hazard if it seeps into people's homes?

DOH is not aware of any residences along the Duwamish river that are being impacted by seeps from the river. Pathogens present in the water column, especially near CSOs following rain events, may represent a potential health concern for individuals using the river for recreational purposes such as swimming or SCUBA diving. Refer to response to question #12.

19. Are there enough data on fish/shellfish tissue to permit an assessment of a health risk and are that data being shared?

While it is always desirable to have more information, DOH determined that sampling of some species of fish in the LDW such as salmon, English sole, and perch were adequate to support recommendations made in this health assessment to protect public health. There was a limited amount of Dungeness crab samples, but recommendations concerning crab consumption are based on red rock crab data. Shellfish are not well-characterized in the LDW, and this health assessment recommends additional sampling of these species.

The tissue data used in this health assessment have a variety of origins. The bulk of it comes from the Puget Sound Ambient Monitoring Program conducted by the Washington State Department of Fish and Wildlife, and the King County water quality assessment. These data are available to the public.

20. Are surface water, combined sewer overflows (CSO), and air issues being addressed?

A number of government agencies are involved with the monitoring, regulation, and management of the LDW site. The Washington State Department of Ecology Toxics Cleanup Program is the lead for addressing upland source control actions that could impact LDW sediment. Impacts to surface water that present no threat to sediments will be addressed by other Ecology programs and/or local agencies. In addition, Ecology issues National Pollutant Discharge Elimination System (NPDES) permits along the shoreline of the LDW. Combined sewer overflows have been evaluated by the King County Department of Natural Resources in a report entitled "Water Quality Assessment for the Duwamish River and Elliott Bay" dated February 1999. A number of documents are included in the water quality assessment, and they can be accessed at the following Internet URL address: <http://dnr.metrokc.gov/wlr/waterres/wqa/wqpage.htm>. Exposure

to chemicals in surface water represents much less of a concern than exposure via ingestion of contaminated seafood. Air issues within the LDW study area fall under the jurisdiction of the Puget Sound Clean Air Agency.

21. What about occupational exposure to fishermen exercising their treaty rights?

On the basis of the exposure assumptions used to evaluate this exposure pathway, exposure to contaminated sediments while tending fishing nets was not expected to result in adverse health effects. Exposure of tribal fisher people are discussed on page 34.

22. Is it safe to eat shellfish?

Two separate advisories concerning shellfish from the King County shoreline (including the LDW) exist. The PH-SKC advisory warns harvesters that shellfish harvested near urban areas along the King County shoreline are potentially contaminated, and the DOH Food Safety and Shellfish Programs advisory recommends against the consumption of shellfish from the King County shoreline except for Vashon-Maury Island. These advisories are based on potential biological and chemical contamination of shellfish as a result of proximity to urban areas. However, the extent of contamination in LDW shellfish is not actually known because of limited shellfish sampling. Shellfish from the LDW should not be eaten until more information is known about them.

23. Can people get cancer or leukemia from eating fish/shellfish from the river?

Certain contaminants present in LDW fish/shellfish are considered to be carcinogenic or to have the potential to cause cancer. The two major contaminants in LDW fish that can or may cause cancer in humans, arsenic and PCBs, are not associated with leukemia but have been linked to other types of cancer. The estimation of cancer risks utilizes science to the maximum extent possible; however, many assumptions are employed in this process. In general, estimated cancer risks associated with eating LDW fish are very low. Furthermore, the risk assessment methodologies used in this PHA are likely to overestimate the true risk of cancer.

Conclusions

1. *People who eat large amounts of resident (nonanadromous) fish caught in the LDW may be at some risk for adverse health effects.* The primary health concern is the potential for adverse effects on the development of children following exposure in the womb. Exposure of the fetus to mercury and PCBs has been shown to impair learning and behavior during childhood. Levels of PCBs found in English sole suggest that consumption of this species, particularly by pregnant women, should be limited. Other bottomfish from the LDW (i.e., flounder) can also be assumed to contain high levels of PCBs. In addition to bottomfish, there is risk associated with consumption of pelagic fish, namely striped perch, from the LDW. Though these fish do not contain levels of PCBs as high as the levels in bottomfish, they represent a slight risk to people who might frequently consume them, such as anglers and subsistence populations. Limited sampling indicates that both red rock and Dungeness crab contain elevated levels of PCBs and

mercury. In addition, Dungeness crab contain elevated levels of arsenic, although the percentage of the more toxic inorganic form is not known. Although it is not clear that the LDW can support a significant shellfish or crab harvest, people have been witnessed harvesting crabs from the LDW. Finally, Quillback rockfish, though not identified in the LDW, also contained high levels of PCBs; therefore, consumption of these fish from Elliot Bay should also be limited. Because a subsistence fish-consuming population can potentially consume significant amounts of resident fish from the LDW, consumption of resident fish from the LDW represents a public health hazard in accordance with ATSDR's conclusion categories.

- ◆ A health advisory from PH-SKC currently exists for urban areas along the King County shoreline warning about contaminants in bottomfish, shellfish, and crab. However, the health advisory has not been well documented or communicated to populations consuming seafood from the LDW. There is also a general advisory from DOH Food Safety and Shellfish Programs that advises against harvesting shellfish from all the King County shoreline except Vashon-Maury Island because of biologic and chemical contamination associated with urban areas. The highest consumers of fish and/or shellfish from the LDW are from Asian/Pacific Islander and Native American communities. With the exception of Boeing Plant 2, signs warning against the consumption of these types of seafood from the LDW were not visible from the shoreline or from the LDW during site visits to the study area.
- ◆ The current PH-SKC advisory includes crab and bottomfish (e.g., English sole), which are among the most contaminated species consumed in the LDW. However, rockfish caught in Elliot Bay contain the highest levels of PCBs, but they are not considered to be bottomfish. DOH is currently evaluating the potential health risk associated with exposure to polychlorinated biphenyls (PCBs) in fish throughout Puget Sound.
- ◆ Salmon are not bottomfish and are not part of the advisory. Recent data indicate that contaminant levels in LDW salmon are similar to those found in salmon from other parts of Puget Sound. DOH is currently evaluating PCB exposure from consumption of salmon caught throughout Puget Sound. Exposure to PCBs in salmon and other fish can be reduced through preparation and cooking.
- ◆ Livers of English sole caught in the LDW contain approximately 25 times the amount of PCBs in muscle tissue. While there is no evidence that livers of fish caught in the LDW are consumed to any great extent, consumption of livers from resident fish caught in the LDW could substantially add to overall PCB exposure.
- ◆ The hepatopancreas organ in crabs concentrates PCBs. A seafood consumption study of Asian and Pacific Islanders in King County indicates that many people eat this organ when consuming crabs. Although sampling in the LDW is limited, data gathered elsewhere indicate that this organ can contain up to 10 times the amount of PCBs found in muscle tissue.

2. Consumption of shellfish from the LDW represents an indeterminate public health hazard. Existing tissue data for shellfish are very limited, representing a significant data gap, and little is known about the type and quantity of shellfish that can potentially be harvested from the LDW.
3. Direct contact with chemicals in LDW sediments (e.g., playing, fishing, or net-fishing) represents no apparent public health hazard. Extensive sediment sampling of the LDW over the past ten years was evaluated for various recreational (swimming, shell-fishing) and occupational (bank restoration, tribal net fishing) exposure scenarios. Geographical Information System (GIS) maps were used to delineate specific areas of exposure in order to calculate an appropriate contaminant concentration for each scenario.
4. Exposure to chemical contaminants in surface water while swimming represents no apparent public health hazard. The water quality assessment conducted by King County determined that there is very little risk to swimmers associated with chemical contaminants in surface water of the LDW. This pathway is unlikely to represent a health hazard because community outreach efforts and site visits found very little evidence that swimming is a frequent activity in the LDW. It is important to note, however, that PH-SKC has a current advisory against swimming near combined sewer outfalls (CSOs) because of high levels of pathogens.
5. The tissue and sediment data evaluated for this public health assessment have not been reviewed by EPA or Ecology. This information will undergo review and evaluation by EPA and Ecology, and it will be reviewed by DOH to ensure that the conclusions of the health assessment remain valid. Additional environmental data collected during Phase II of the remedial investigation/feasibility study and early action activities will also be evaluated by DOH.
6. Common concerns expressed during community interviews and outreach activities related to the safety of consuming salmon harvested from the LDW, the safety of seafood consumed from local markets, and a lack of information warning against consumption of seafood harvested from the LDW study area.
7. Building relationships with all populations potentially impacted by contamination at the LDW site is imperative. DOH has committed to revisiting every community group previously contacted in order to present the findings of this public health assessment. All community groups expressed interest in receiving public health messages outlined in the public health assessment. Several of the Asian/Pacific Islander groups are interested in learning more about safe shellfish harvesting. An excellent video, *Good Food From the Beach: Safe and Responsible Marine Resource Harvesting*, is available through the Washington Department of Fish and Wildlife in English, Korean, Samoan, Vietnamese, and Cambodian. DOH plans to view the video with interested communities and offer helpful tips from the DOH shellfish experts in addition to presenting the results of the health assessment.
8. Vietnamese and Filipino groups requested written educational materials. DOH will coordinate with *The Voice* newspaper, which serves housing communities in High Point, Park

Lake Homes, Rainier Vista, among others, and offers translations in Amharic, Cambodian, Russian, Somali, Tigrigna, and Vietnamese to communicate health messages regarding the LDW. The *Filipino American Bulletin* has also offered to publish community health messages regarding the LDW. Radio and television service announcements are also possibilities that DOH will explore.

Recommendations

1. DOH supports King County's existing advisory that warns of contaminants in shellfish, bottomfish, and crabs near urban areas of the King County shoreline. The DOH Office of Food Safety and Shellfish Programs has also issued a general shellfish advisory for the entire King County shoreline, except Vashon-Maury Island. This assessment further recommends the following advisory related to consumption of LDW fish:
 - ◆ Consumption of any resident fish from the LDW should be limited to one 8-ounce meal per month (see table 10), and quillback rockfish from Elliot Bay near Harbor Island should be avoided. Women who are pregnant or considering pregnancy should pay special attention to these meal limits because PCBs and mercury, the contaminants on which the meal limits are based, can impair development of the fetus.
 - ◆ People who routinely eat fish in their diet should avoid eating any resident fish from the LDW to account for the fact that all fish, including those purchased at the supermarket, have some contaminants.
 - ◆ Salmon is the preferred fish to eat from the LDW, but it should not be eaten every day, especially while a consumer is pregnant or considering pregnancy.
 - ◆ The hepatopancreas of crabs should not be eaten because of the tendency for PCBs to concentrate in the organ.
 - ◆ Livers from bottomfish caught in the LDW should not be eaten because of the likelihood of highly concentrated contamination.
 - ◆ In concurrence with both PH-SKC and DOH Food Safety and Shellfish Programs, consumption of shellfish from the LDW should be avoided because of potential chemical and biological contamination.
2. Further investigation is needed to permit an adequate assessment of exposure from consumption of certain species caught in the LDW. In addition, more information regarding the extent of consumption of shellfish is necessary to determine if this pathway is of concern.
 - ◆ The abundance of shellfish within the LDW needs to be determined.
 - ◆ Congener-specific analysis for PCBs is needed for a representative species from each

of the various trophic levels of the LDW.

3. A current inventory of existing warning signs within the LDW study needs to be conducted. The specific location of each sign needs to be documented, the language of each sign needs to be identified, and the specific health messages should be accurately verified by a translator.
4. Educational information should be provided to populations potentially impacted by LDW contamination. These materials should communicate the existing health advisories and findings of the public health assessment.
5. Signs communicating concerns about the consumption of fish and shellfish from the LDW should be posted where fishing is known or likely to occur.
6. DOH will evaluate new environmental data gathered by various agencies within the LDW study area.
7. Very little is known about how much fish is being caught and eaten from the LDW, but evidence of people fishing and crabbing in the LDW, combined with the presence of elevated contaminant levels, has prompted a fish advisory. As the fish advisory becomes better communicated, an evaluation of the effectiveness of the advisory should be conducted.

Public Health Action Plan

The public health action plan for the Lower Duwamish Waterway site identifies actions to be taken by DOH and other government agencies. The purpose of the action plan is to ensure that the public health assessment not only identifies public health hazards, but also provides a plan of action designed to mitigate and prevent adverse human health effects resulting from exposure to hazardous substances in the environment. The following public health actions are based upon the recommendations outlined in this public health assessment.

1. DOH will re-examine the consumption limits recommended in this health assessment pending new sampling and/or toxicological data.
2. DOH will revisit all community groups previously contacted to present the conclusions and recommendations of this public health assessment.
3. DOH will post signs.
4. DOH will provide health education materials to various community groups to assist in communicating health messages. Educational materials will be translated into various languages and will be verified for technical accuracy by a translator.
 - ◆ DOH will coordinate shellfish harvesting and safety education presentations, including showing a marine resource harvesting video in a community's native language, to those groups that requested harvesting information.

- ◆ DOH will conduct fish-cleaning demonstrations to show the affected community how to reduce its exposure to contaminants in fish.
- 5. ATSDR and DOH will explore the possibility of sponsoring a continuing medical education (CME) session designed to educate physicians on how to evaluate environmental exposures.
- 6. DOH will coordinate with PH-SKC, EPA, and Ecology to implement the recommendations outlined in this public health assessment.
- 7. Community repositories for the public health assessment and related fact sheets will be established at the following locations:

Boulevard Park Library
12015 Roseberg Ave. S.
Seattle, WA 98168
(206) 242-8662

South Park Community Center
8319 8th Ave. S.
Seattle, WA 98101
(206) 684-7451

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Appendix A: Figures

Figure 1.

Figure 2a.

Figure 2b.

Figure 2c.

Figure 2d.

Figure 2e.

Figure 2f.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Appendix B: Site Photographs

Appendix C: Exposure Assumptions and Dose Calculations

This section provides calculated exposure doses and assumptions used for each completed exposure pathway. The dose estimates for each pathway are discussed under the Pathways Analysis/Public Health Implications section. The following exposure parameters and dose equations were used to estimate exposure from fish consumption and direct contact with sediments at the LDW site.

___Fish Consumption

Average and upper-bound exposure scenarios were evaluated for consumption of fish from the LDW site. Because site-specific consumption rates for fish caught from the LDW study area were lacking, surrogate rates were taken from a recent survey of the Suquamish Tribe, using data gathered from fish consumers only, and a study of recreational anglers in urban embayments of Puget Sound. Exposure assumptions given in Table C1 below were used with Equations C1 and C2 to estimate contaminant doses associated with fish consumption.

$$\text{Dose}_{\text{(non-cancer (mg/kg-day))}} = \frac{C \times CF_1 \times IR \times CF_2 \times EF \times ED}{AT_{\text{non-cancer}}} \quad \text{Equation C1}$$

$$\text{Dose}_{\text{(cancer (mg/kg-day))}} = \frac{C \times CF_1 \times IR \times CF_2 \times EF \times ED}{AT_{\text{cancer}}} \quad \text{Equation C2}$$

Table C1. Exposure assumptions used to estimate contaminant doses from consumption of fish from the Lower Duwamish Waterway, Seattle, Washington

Parameter	Value		Units	Comments
	Average	High-end		
Concentration (C)	Species specific		ug/kg	See Table C2. Below.
Conversion Factor ₁ (CF ₁)	0.001	0.001	mg/ug	Converts concentration from
Ingestion Rate (IR) - English Sole	0.08 ^a	0.201	g/kg/day	a = Recreational rates from Landolt et al assuming fishing season of 120 days for salmon and 183 days for other species. Remaining average ingestion rates based on median rates from the Suquamish Tribe. High-end based on 90 th percentile rates from the Suquamish Tribe fish consumers.
Ingestion Rate (IR) - Coho	0.15 ^a	0.584		
Ingestion Rate (IR) - Chinook	0.25 ^a	0.581		
Ingestion Rate (IR) - All rockfish	0.12 ^a	0.728		
Ingestion Rate (IR) - Red Rock Crab	0.012	0.117		
Ingestion Rate (IR) - Dungeness Crab	0.071	0.425		
Ingestion Rate (IR) - Mussels	0.015	0.155		
Ingestion Rate (IR) - Perch	0.26 ^a	0.014		
Conversion Factor (CF ₂)	0.001	0.001	kg/g	Converts mass of fish from grams (g) to kilograms (kg)
Exposure Frequency (EF)	365	365	days/year	Assumes daily exposure consistent with units of ingestion rate given in g/kg/day.
Exposure Duration (ED)	30	55	years	Estimates of residence time.
Averaging Time _{non-cancer} (AT)	10950	20075	days	Residence time in years
Averaging Time _{cancer} (AT)	25550	25550	days	70 year lifetime

a = consumption rates from Landolt et al were reported as g/day during the fishing season. A body weight of 72 kg was used to convert the units to g/kg/day.

Contaminant concentrations used to estimate exposure to contaminants in Duwamish River fish are given below in Table C2. These concentrations are based on data compiled from various sources as part of the scoping-phase risk assessment in preparation for the Remedial Investigation. For finfish, only data generated from analysis of fillets without skin were used. Crab data included analytical results from muscle tissue only.

A majority of the finfish samples were analyzed as composite samples, meaning that several fish were collected and blended together in order to obtain an approximation of the mean contaminant concentration in a group of fish. This method reduces the cost of environmental analyses, but it decreases the knowledge about the variability of contaminant levels in a fish population. This health assessment relied on both composite and individual samples. As a result, a weighting method was used to calculate mean contaminant concentrations in finfish. Estimates of variance around the mean were also calculated in order to estimate confidence intervals around the mean. The equations and examples are shown below.

Weighted mean (grouped mean)

$$\bar{x} = (\sum CN) / (\sum N)$$

The weighted mean is equal to the sum of composite sample concentration times the number of fish per composite divided by the sum of fish per composite in all samples.

For example:

The weighted mean concentration of the following data set is shown below.

Sample	Fish per composite	Concentration
1	2	100
2	8	52
3	10	48

$$\text{Weighted mean concentration} = (2*100 + 8*52 + 10*48) / 20 \\ = 54.8$$

Grouped Variance

$$(\sum C^2N - ((\sum CN)^2/n))/(n-1)$$

Using the above example:

$$\text{Grouped variance} = \{ (2*(100)^2 + 8*(52)^2 + 10*(48)^2) - (((2*100)^2 + (8*52)^2 + (10*48)^2)/20) \} / 19$$

The 95 UCL was calculated for groups of composited fish samples, using the weighted mean and the grouped variance. In general, composite sampling is designed to get a better approximation of the mean; therefore, the 95 UCL was not much greater than the weighted mean.

Table C2. Contaminant concentrations used to estimate exposure from consumption of fish from the Lower Duwamish Waterway, Seattle, Washington

Fish Species	Arsenic ^a (mg/kg)			Cadmium (mg/kg)			Chlordane (ug/kg)			cPAHs (ug/kg)			DDE (ug/kg)			Mercury ^c (ug/kg)			Total PCBs ^b (ug/kg)		
	Mean	95 UCL	n	Mean	95 UCL	n	Mean	95 UCL	n	Mean	95 UCL	n	Mean	95 UCL	n	Mean	95 UCL	n	Mean	95 UCL	n
English sole	10	12	9	0.02	0.05	3	1.1	1.3	9	26	41	6	2.7	5.9	9	54	61	24	267	312	21
Coho	0.8	0.9	18	NA	NA	NA	0.9	1.1	57	42	45	16	8.3	9	57	32	37	16	39	45	45
Chinook	1	1.2	18	NA	NA	NA	1.2	1.3	83	41	44	19	19	22	83	102	124	18	55	64	65
Quillback rockfish	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04	0.04	1	408	438	8	292	336	5
Red Rock Crab	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	63	88	9	110	152	9
Dungeness Crab ^f	9.9	12.5 ^f	2	0.02	0.02	2	NA	NA	NA	40	40	2	NA	NA	NA	90	110	3	130	177	3
Mussels	0.8	0.9	63	0.43	0.47	63	3.4		27	42	43	62	0.7	0.7	27	11	15	62	29	34	60
Perch ^g	1.3	1.4 ^f	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15	20	9	111	140	9

a = Arsenic concentrations are given as total arsenic. Ten percent of this value was used in dose calculations to represent the amount of inorganic arsenic, to be consistent with EPA's RfD and cancer slope factor, both of which are based on exposure to inorganic arsenic.

b = Sum of Aroclors. The predominant Aroclors detected in Puget Sound fish are Aroclor 1254 and Aroclor-1260

c = Mercury concentrations are given as total mercury. All measured mercury is assumed to be in the methylmercury form for comparison with EPA's RfD for methylmercury.

f = Represents maximum value detected.

g = striped perch

Table C3. Noncancer dose calculations for consumption of fish from the Lower Duwamish Waterway, Seattle, Washington

Receptor Population	Fish Species	Contaminant	Concentration		Estimated Dose (mg/kg-day)		RfD (mg/kg-day)	Hazard Quotient	
			Average	High-end	Average	High-end		Average	High-end
Fish Consumers	English Sole	Arsenic	10	12	8e-05	2e-04	3e-04	0.3	0.8
		Cadmium	0.02	0.05	2e-09	1e-08	1e-03	2e-06	1e-05
		Chlordane	1.1	1.3	9e-08	3e-07	5e-04	2e-04	5e-04
		Total PCBs	267	312	2e-05	6e-05	2e-05	1.1	3.1
		Mercury	54	61	4e-06	1e-05	1e-04	0.04	0.1
		Hazard Index						1.4	4.1
	Chinook Salmon (King)	Arsenic	1	1.2	3e-05	7e-05	3e-04	0.1	0.2
		Cadmium	NA	NA	NA	NA	1e-03	NA	NA
		Chlordane	1.2	1.3	3e-07	8e-07	5e-04	6e-04	2e-03
		Total PCBs	55	64	1e-05	4e-05	2e-05	0.7	1.9
		Mercury	102	124	3e-05	7e-05	1e-04	0.3	0.7
		Hazard Index ¹						1.0	2.8
	Coho Salmon	Arsenic	0.8	0.9	1e-05	5e-05	3e-04	0.04	0.2
		Cadmium	NA	NA	NA	NA	1e-03	NA	NA
		Chlordane	1.1	1.3	1e-07	6e-07	5e-04	3e-04	1e-03
		Total PCBs	39	45	6e-06	3e-05	2e-05	0.3	1.3
		Mercury	32	37	5e-06	2e-05	1e-04	0.05	0.2
		Hazard Index						0.4	1.7
	Rockfish	Arsenic	NA	NA	NA	NA	3e-04	NA	NA
		Cadmium	NA	NA	NA	NA	1e-03	NA	NA
		Chlordane	NA	NA	NA	NA	5e-04	NA	NA
		Total PCBs	292	336	4e-05	2e-04	2e-05	1.8	12.2
		Mercury	408	438	5e-05	3e-04	1e-04	0.5	3.2
		Hazard Index						2.3	15.4
	Red Rock Crab	Arsenic	NA	NA	NA	NA	3e-04	NA	NA
		Cadmium	NA	NA	NA	NA	1e-03	NA	NA
		Chlordane	NA	NA	NA	NA	5e-04	NA	NA
		Total PCBs	110	152	1e-06	2e-05	2e-05	0.1	0.9
		Mercury	63	88	8e-07	1e-05	1e-04	1e-02	0.1
		Hazard Index						0.1	1.0
	Dungeness Crab	Arsenic	9.9	12.5	7e-05	5e-04	3e-04	0.2	1.8
		Cadmium	0.02	0.02	1e-09	9e-09	1e-03	1e-06	1e-05
		Chlordane	NA	NA	NA	NA	5e-04	NA	NA
		Total PCBs	130	177	9e-06	7e-05	2e-05	0.5	3.8
		Mercury	90	110	6e-06	5e-05	1e-04	0.1	0.5
		Hazard Index						0.8	6.0
	Mussels	Arsenic	0.8	0.9	1e-06	1e-05	3e-04	4e-03	0.04
		Cadmium	0.43	0.47	7e-09	7e-08	1e-03	1e-05	7e-05
		Chlordane	3.4	3.4	5e-08	5e-07	5e-04	1e-04	1e-03
		Total PCBs	29	34	4e-07	5e-06	2e-05	0.02	0.3
		Mercury	11	15	2e-07	2e-06	1e-04	2e-03	0.02
		Hazard Index						0.03	0.3

	Perch	Arsenic	1.3	1.4	3e-05	2e-06	3e-04	0.1	0.01
		Cadmium	NA	NA	NA	NA	1e-03	NA	NA
		Chlordane	NA	NA	NA	NA	5e-04	NA	NA
		Total PCBs	111	140	3e-05	2e-06	2e-05	1.4	0.1
		Mercury	15	20	4e-06	3e-07	1e-04	0.04	3e-03
		Hazard Index							1.6

Note: Rounding of hazard quotients could impact the hazard index. Doses are reported in scientific notation format. For example, 1e-02 is the same as 1×10^{-2} or 0.01.

Table C4. Cancer risk calculations for consumption of fish from the Lower Duwamish Waterway, Seattle, Washington

Receptor Population	Fish Species	Contaminant	Concentration ^a		Estimated Dose (mg/kg-day)		Cancer Slope Factor (mg/kg-day) ⁻¹	Cancer Risk	
			Average	High-end	Average	High-end		Average	High-end
Fish Consumers	English Sole	Arsenic	10	12	3e-05	2e-04	1.5	5e-05	3e-04
		cPAHs	26	41	9e-07	7e-06	7.3	7e-06	5e-05
		Chlordane	1.1	1.3	4e-08	2e-07	0.35	1e-08	7e-08
		DDE	2.7	5.9	9e-08	9e-07	0.34	3e-08	3e-07
		Total PCBs	267	312	9e-06	5e-05	2	2e-05	1e-04
		Sum of Cancer Risks						8e-05	4e-04
	Chinook Salmon (King)	Arsenic	1	1.2	1e-05	6e-05	1.5	2e-05	8e-05
		cPAHs	41	44	4e-06	2e-05	7.3	3e-05	1e-04
		Chlordane	1.2	1.3	1e-07	6e-07	0.35	5e-08	2e-07
		DDE	19	22	4e-06	2e-05	0.34	2e-06	7e-06
		Total PCBs	55	64	6e-06	3e-05	2	1e-05	6e-05
		Sum of Cancer Risks						6e-05	3e-04
	Coho Salmon	Arsenic	0.8	0.9	5e-06	4e-05	1.5	7e-06	6e-05
		cPAHs	42	45	3e-06	2e-05	7.3	2e-05	2e-04
		Chlordane	0.9	1.1	6e-08	5e-07	0.35	2e-08	2e-07
		DDE	8.3	9	5e-07	4e-06	0.34	2e-07	1e-06
		Total PCBs	39	45	2e-06	2e-05	2	5e-06	4e-05
		Sum of Cancer Risks						3e-05	3e-04
	Rockfish	Arsenic	NA	NA	NA	NA	1.5	NA	NA
		cPAHs	NA	NA	NA	NA	7.3	NA	NA
		Chlordane	NA	NA	NA	NA	0.35	NA	NA
		DDE	0.04	0.04	2e-09	2e-08	0.34	7e-10	8e-09
		Total PCBs	292	336	2e-05	2e-04	2	3e-05	4e-04
		Sum of Cancer Risks						3e-05	4e-04
	Red Rock Crab	Arsenic	NA	NA	NA	NA	1.5	NA	NA
		cPAHs	NA	NA	NA	NA	7.3	NA	NA
		Chlordane	NA	NA	NA	NA	0.35	NA	NA
		DDE	NA	NA	NA	NA	0.34	NA	NA
		Total PCBs	110	152	6e-07	1e-05	2	1e-06	3e-05
		Sum of Cancer Risks						1e-06	3e-05
	Dungeness Crab	Arsenic	10	12.5	3e-05	4e-04	1.5	5e-05	6e-04
		cPAHs	40	40	1e-06	1e-05	7.3	9e-06	1e-04
		Chlordane	NA	NA	NA	NA	0.35	NA	NA
		DDE	NA	NA	NA	NA	0.34	NA	NA
		Total PCBs	130	177	4e-06	6e-05	2	8e-06	1e-04
		Sum of Cancer Risks						6e-05	8e-04
	Mussels	Arsenic	0.8	0.9	5e-07	1e-05	1.5	8e-07	2e-05
		cPAHs	42	43	3e-07	5e-06	7.3	2e-06	4e-05
		Chlordane	3.4	3.4	2e-08	4e-07	0.35	8e-09	1e-07
		DDE	0.7	0.7	5e-09	9e-08	0.34	2e-09	3e-08
		Total PCBs	29	34	2e-07	4e-06	2	4e-07	8e-06
		Sum of Cancer Risks						3e-06	6e-05

Receptor Population	Fish Species	Contaminant	Concentration ^a		Estimated Dose (mg/kg-day)		Cancer Slope Factor (mg/kg-day) ⁻¹	Cancer Risk	
			Average	High-end	Average	High-end		Average	High-end
Fish Consumers	Perch	Arsenic	1.3	1.4	1e-05	2e-06	1.5	2e-05	2e-06
		cPAHs	NA	NA	NA	NA	7.3	NA	NA
		Chlordane	NA	NA	NA	NA	0.35	NA	NA
		DDE	NA	NA	NA	NA	0.34	NA	NA
		Total PCBs	111	140	1e-05	2e-06	2	2e-05	3e-06
								5e-05	5e-06

a = Arsenic concentrations are given in units of mg/kg, while PCB values are in ug/kg.

Note—Cancer risks are reported in scientific notation format. For example, 1e-02 is the same as 1×10^{-2} or 0.01.

Table C5. Exposure assumptions used to estimate contaminant doses from consumption of fish groups from the Lower Duwamish Waterway, Seattle, Washington

Parameter	Value			Units	Comments
	Average	API	High-end		
Concentration (C)	<i>Species specific</i>			ug/kg	See Table C6. Below.
Conversion Factor ₁ (CF ₁)	0.001	0.001	0.001	mg/ug	Converts concentration from
Ingestion Rate (IR) - Anadromous	0.35	0.509	1.68	g/kg/day	Median and 90 th percentile rates from the Suquamish Tribe and 90 th percentile rates from Asian Pacific Islander Seafood Consumption Study
Ingestion Rate (IR) - Benthic	0.042	0.272	0.392		
Ingestion Rate (IR) - Pelagic	0.068	0.829	0.403		
Ingestion Rate (IR) - Shellfish	0.75	1.73	4.58		
Conversion Factor (CF ₂)	0.001	0.001	0.001	kg/g	Converts mass of fish from grams (g) to kilograms (kg)
Exposure Frequency (EF)	365	365	365	days/year	Assumes daily exposure consistent with units of ingestion rate given in g/kg/day.
Exposure Duration (ED)	30	30	55	years	Estimates of residence time.
Averaging Time _{non-cancer} (AT)	10950	10950	20075	days	Residence time in days
Averaging Time _{cancer} (AT)	25550	25550	25550	days	70 years

Table C6. Noncancer dose calculations for consumption of fish groups from the Lower Duwamish Waterway, Seattle, Washington

Receptor Population	Fish Group	Contaminant	Concentration			Estimated Dose (mg/kg-day)			RfD (mg/kg-day)	Hazard Quotient		
			Average	API	High-end	Average	API	High-end		Average	API	High-end
Fish Consumers	All Salmon	Arsenic	1	1.2	1.2	4e-05	6e-05	2e-04	3e-04	0.1	0.2	0.7
		Cadmium	NA	NA	NA	NA	NA	NA	1e-03	NA	NA	NA
		Chlordane	1.2	1.3	1.3	4e-07	7e-07	2e-06	5e-04	8e-04	1e-03	4e-03
		Total PCBs	55	64	64	2e-05	3e-05	1e-04	2e-05	1.0	1.6	5.4
		Mercury	102	124	124	4e-05	6e-05	2e-04	1e-04	0.4	0.6	1.9
	Hazard Index									1.4	2.4	8.0
	Pelagic	Arsenic	1.3	1.4	1.4	9e-06	1e-04	6e-05	3e-04	0.03	0.4	0.2
		Cadmium	NA	NA	NA	NA	NA	NA	1e-03	NA	NA	NA
		Chlordane	NA	NA	NA	NA	NA	NA	5e-04	NA	NA	NA
		Total PCBs	111	140	140	8e-06	1e-04	6e-05	2e-05	0.4	5.8	2.8
		Mercury	15	20	20	1e-06	2e-05	8e-06	1e-04	0.01	0.2	0.08
	Hazard Index									0.4	6.4	3.1
	Benthic	Arsenic	10	12	12	4e-05	3e-04	5e-04	3e-04	0.1	0.9	1.6
		Cadmium	0.02	0.05	0.05	8e-10	5e-09	2e-08	1e-03	1e-06	5e-06	2e-05
		Chlordane	1.1	1.3	1.3	5e-08	3e-07	5e-07	5e-04	1e-04	6e-04	1e-03
		Total PCBs	267	312	312	1e-05	9e-05	1e-04	2e-05	0.6	4.2	6.1
		Mercury	54	61	61	2e-06	2e-05	2e-05	1e-04	0.02	0.15	0.2
	Hazard Index									0.7	5.3	7.9
	Shellfish	Arsenic	0.8	0.9	0.9	6e-05	1e-04	4e-04	3e-04	0.2	0.5	1.3
		Cadmium	0.43	0.47	0.47	3e-06	6e-06	2e-05	1e-03	5e-03	0.01	0.03
		Chlordane	3.4	3.4	3.4	6e-05	1e-04	4e-04	5e-04	0.2	0.5	1.3
		Total PCBs	29	34	34	2e-05	6e-05	2e-04	2e-05	1.1	2.9	7.8
		Mercury	11	15	15	8e-06	3e-05	7e-05	1e-04	0.08	0.3	0.7
	Hazard Index									1.4	3.7	9.8

Note—Doses are reported in scientific notation format. For example, 1e-02 is the same as 1 x 10⁻² or 0.01.

Table C7. Cancer dose calculations for consumption of fish groups from the Lower Duwamish Waterway, Seattle, Washington

Receptor Population	Fish Group	Contaminant	Concentration ^a			Estimated Dose (mg/kg-day)			Cancer Slope Factor (mg/kg-day ⁻¹)	Cancer Risk		
			Average	API	High-end	Average	API	High-end		Average	API	High-end
Fish Consumers	Anadromous	Arsenic	1	1.2	1.2	2e-05	3e-05	2e-04	1.5	2e-05	4e-05	2e-04
		cPAHs	41	44	44	6e-06	1e-05	6e-05	7.3	4e-05	7e-05	4e-04
		Chlordane	1.2	1.3	1.3	2e-07	3e-07	2e-06	0.35	6e-08	1e-07	6e-07
		DDE	19	22	22	6e-06	1e-05	6e-05	0.34	2e-06	3e-06	2e-05
		Total PCBs	55	56	56	8e-06	1e-05	8e-05	2	2e-05	3e-05	2e-04
		Sum of Cancer Risks								9e-05	1e-04	9e-04
	Pelagic	Arsenic	1.3	1.4	1.4	4e-06	5e-05	4e-05	1.5	6e-06	7e-05	7e-05
		cPAHs	NA	NA	NA	NA	NA	NA	7.3	NA	NA	NA
		Chlordane	NA	NA	NA	NA	NA	NA	0.35	NA	NA	NA
		DDE	NA	NA	NA	NA	NA	NA	0.34	NA	NA	NA
		Total PCBs	111	140	140	3e-06	5e-05	4e-05	2	6e-06	1e-04	9e-05
		Sum of Cancer Risks								1e-05	2e-04	1e-04
	Benthic	Arsenic	10.9	12.1	12.1	2e-05	1e-04	4e-04	1.5	3e-05	2e-04	6e-04
		cPAHs	26	41	41	5e-07	5e-06	1e-05	7.3	3e-06	3e-05	9e-05
		Chlordane	1.1	1.3	1.3	2e-08	2e-07	4e-07	0.35	7e-09	5e-08	1e-07
		DDE	2.7	5.9	5.9	5e-08	7e-07	2e-06	0.34	2e-08	2e-07	6e-07
		Total PCBs	267	312	312	5e-06	4e-05	1e-04	2	1e-05	7e-05	2e-04
		Sum of Cancer Risks								4e-05	3e-04	8e-04
	Shellfish	Arsenic	0.8	0.9	0.9	3e-05	7e-05	3e-04	1.5	4e-05	1e-04	5e-04
		cPAHs	42	43	43	1e-05	3e-05	1e-04	7.3	1e-04	2e-04	1e-03
		Chlordane	3.4	3.4	3.4	1e-06	3e-06	1e-05	0.35	4e-07	9e-07	4e-06
		DDE	0.7	0.7	0.7	2e-07	5e-07	3e-06	0.34	8e-08	2e-07	9e-07
		Total PCBs	29	34	34	9e-06	3e-05	1e-04	2	2e-05	5e-05	2e-04
										2e-04	4e-04	2e-03

Note—Doses are reported in scientific notation format. For example, 1e-02 is the same as 1 x 10⁻² or 0.01.

Fish Consumption Limits

Several contaminants of concern are present in fish from the LDW; therefore, the most conservative recommended fish ingestion rate is the amount of a fish that one can consume that results in a hazard index of 1.0. However, all the contaminants of concern in fish do not have the same toxic effects, so that it may not be appropriate to determine consumption limits based on the hazard index for all COCs. Therefore, consumption limits were calculated based on developmental and immunologic endpoints for PCBs, mercury, and DDE. Consumption rates were calculated for both average and high-end estimates of contaminant concentration for each species, using Equation C3 in conjunction with the MRL or RfD as the target risk value and the exposure parameters provided in the table below. The developmental and immunologic endpoints are based on the additive effects of PCBs, mercury, and DDE as recommended in the draft ATSDR interaction profile for toxic contaminants found in fish. Table C9 provides fish consumption rates that would be protective of people who eat fish from the LDW.

$$\text{Recommended fish consumption (meals per month)} = \frac{\text{Rfd or MRL} * 30.4 * \text{BW}}{\text{meal size} * C} \quad \text{Equation C3}$$

Table C8. Exposure parameters used to calculate recommended Lower Duwamish Waterway fish consumption limits

Exposure Parameter	Endpoint		Units
	Developmental	Immunologic	
Concentration (C)	variable	variable	ug/kg
Minimal Risk Level (MRL) - PCBs	0.03	0.02	ug/kg/day
mercury	0.1	0.3	
DDE	2	2	
Days per month	30.4	30.4	days/month
Body Weight (BW)	60	70	kg
Meal size	0.227	0.227	kg

Many factors must be considered when one is recommending limits on the consumption of fish, including the very real health benefits of eating fish, the quality and comprehensiveness of environmental data, and the availability of alternate sources of nutrition. In addition, these limits do not consider that multiple species are consumed, a consideration that would require weighting of the percent of each species consumed. These allowable ingestion rates also do not consider the fact that cooking reduces exposure to contaminants in fish. Therefore, allowable consumption limits for prepared fish would be greater than those shown in the tables below.

The consumption limits in the tables below also do not account for the fact that the majority of fish consumers are not likely to obtain all their seafood from the LDW. Some fish from other areas of Puget Sound or the Pacific Ocean are likely to contain lower levels of contaminants; therefore, more fish meals than shown in the tables would be acceptable. Recommendations regarding consumption of fish can be found in the recommendations section of this health assessment.

Table C9. Adult fish consumption limits for the Lower Duwamish Waterway, Seattle, Washington based on exposure to PCBs, mercury, and DDE ^a

Fish Species	Recommended 8 ounce meals per month (Developmental Endpoint)		Recommended 8 ounce meals per month (Immune Endpoint)	
	Average	95 UCL	Average	95 UCL
English Sole	0.9	0.7	0.7	0.6
Rockfish	0.6	0.5	0.6	0.5
Coho	5.0	4.3	4.8	3.9
Chinook	2.9	2.4	3.2	2.6
Red Rock Crab	1.9	1.4	1.6	1.2
Dungeness Crab	1.5	1.1	1.4	1.0
Mussels	7.5	6.3	6.3	5.4
Perch	2.1	1.7	1.7	1.3

a = Consumption limit based on a target hazard index of 1.0.

Direct Contact with Sediment

Upper-bound exposure scenarios were evaluated for direct contact with sediment from the LDW site. Because recreational and crabbing activities occur at a few select areas, site-specific sediment contaminant concentrations were used to estimate exposure. Exposure assumptions given in Table C10 were used with the equations below to estimate contaminant doses associated with direct sediment contact. Doses received from the ingestion and dermal routes were summed to obtain a single dose associated with direct sediment contact.

$$\text{Ingested Dose}_{(\text{non-cancer (mg/kg-day)})} = \frac{\text{CS} * \text{IR} * \text{CF}_1 * \text{EF} * \text{ED}}{\text{BW} * \text{AT}_{\text{non-cancer}}} \quad \text{Equation C4}$$

$$\text{Dermal Dose}_{(\text{non-cancer (mg/kg-day)})} = \frac{\text{CS} * \text{AF} * \text{ABS} * \text{AD} * \text{CF}_2 * \text{EF} * \text{ED} * \text{SA}}{\text{ORAF} * \text{BW} * \text{AT}_{\text{non-cancer}}} \quad \text{Equation C5}$$

$$\text{Ingested Dose}_{(\text{cancer (mg/kg-day)})} = \frac{\text{CS} * \text{IR} * \text{CF}_1 * \text{EF} * \text{ED}}{\text{BW} * \text{AT}_{\text{cancer}}} \quad \text{Equation C6}$$

$$\text{Dermal Dose}_{(\text{cancer (mg/kg-day)})} = \frac{\text{CS} * \text{AF} * \text{ABS} * \text{AD} * \text{CF}_2 * \text{EF} * \text{ED} * \text{SA}}{\text{ORAF} * \text{BW} * \text{AT}_{\text{cancer}}} \quad \text{Equation C7}$$

Table C10. Exposure assumptions used to estimate contaminant doses from direct contact with Lower Duwamish Waterway sediments

Parameter	Units	Tribal Netfishing	Recreational ^a	Shellfishing/ Crabbing ^b
Sediment Concentration (CS)	mg/kg	95 th UCL of LDW sediments	95 th percentile of site specific sediments	95 th percentile of site specific sediments
Soil Ingestion Rate (IR)	mg/day	50	200	50
Conversion Factor (CF ₁)	kg/mg	0.000001	0.000001	0.000001
Exposure Frequency (EF)	days	30/119 ^c	41 ^g	52
Exposure Duration (ED)	years	10/44 ^c	5	25
Body Weight (BW)	kg	41/72 ^d	15	41/72 ^d
Averaging Time (AT) -non-cancer	days	3650/16060	1825	9125
Averaging Time (AT) cancer	days	27375	27375	27375
Surface Area (SA)	cm ²	2900/3850 ^e	2000	2900 / 5700 ^e
Adherence Factor (AF)	mg/cm ²	0.25 ^f	0.2	0.25
24 hr Absorption Factor (ABS)	unitless	Chemical Specific SVOCs - 0.1 Arsenic 0.03 Inorganic - 0.01 PAHs - 0.13 PCBs - 0.14		
Conversion Factor (CF ₂)	kg/mg	0.000001	0.000001	0.000001
Adherence Duration (AD)	days	1	1	1
Oral route adjustment factor	unitless	1	1	1

a = Recreational exposure doses were calculated using concentrations terms specific to particular areas of the river accessed by the public, based on community outreach information.

b = Shellfishing exposure doses were calculated using concentration terms specific to intertidal sediments surrounding Kellogg Island

c = 119 days of fishing for 44 years reported by Muckleshoot Tribe, and 30 days per year during childhood for 10 years (worst-case), based on communication with Suquamish and professional judgement.

d = Body weights of an older child and an adult used in scenario

e = Surface areas of older child and adult used in scenario

f = Adjusted from Reed Gatherer population (Exposure Factors Handbook EPA)

g = EPA comments to LDWG January 23, 2002

Many of the exposure assumptions used in calculating exposure doses were based on default values provided in the Exposure Factors Handbook, Volumes I and III. Adjustments were made to some of these assumptions based on site-specific information and professional judgment. In the tribal net-fisher exposure scenario, fisher people were adults participating in this occupation for 44 years over the period of their lifetime. It was assumed that net-fishing occurs on the river as many as 119 times per year, an assumption based on comments provided by the Muckleshoot Tribe on the LDWG scoping document (Muckleshoot). The 95th UCL concentrations of combined intertidal and subtidal sediments from the entire LDW were considered when calculating a net-fisher's exposures to each of the contaminants of concern. An exposure dose was also calculated that accounted for children who accompany adult fisher people, as indicated by comments from the Suquamish Tribe. In this scenario, it was assumed that children were

fishing 30 days per year for 10 years. The resulting exposure doses were summed with those of the adult scenario to provide a worst-case dose estimate.

The surface area of skin (SA) exposed was based on the assumption that fisher people had exposed face, neck, hands, forearms, and lower legs in the warmer months (~ 5700 cm²) and face and hands only in the cooler months (~2000 cm). It was assumed that half of fishing season was conducted during the warmer months and half in the cooler months, for an average surface area of 3850 cm². This is likely an overestimate of exposed skin, because the Suquamish Tribe fishers claim that they wear full impermeable pants and jackets as well as work gloves year-round.

The adherence factor (AF) for fisher people was weighted by body part, based on the reed gatherer population presented in Exposure Factors Handbook (EFH). There was no reported AF for the face or neck in the study, so that a gardening scenario was chosen to approximate AF for those portions of the body.

It should be noted that RfDs and oral cancer potency factors are not available for the dermal route of exposure. While a dermal dose represents the amount that is *absorbed* into the body, an oral dose is the amount that is *ingested*. In most cases, only a fraction of the ingested dose is absorbed through the gastro-intestinal tract. The fraction that is absorbed in the gut depends largely on the chemical and the medium in which it is ingested (e.g., food, water, soil, etc.) RfDs and oral cancer potency factors are often based on the amount that an animal/human ingests orally, not the amount absorbed in the gut. Dermal doses are based on the amount absorbed through the skin. Therefore, using the oral RfD in conjunction with a dermal dose may underestimate the potential for adverse health effect resulting from dermal exposure. Adjustment factors can be applied to account for the difference in exposure routes, but in the case of the LDW sediment contaminants of concern, Risk Assessment Guidance for Superfund part E does not recommend an adjustment for these chemicals.

Table C11. Noncancer hazard calculations for exposure to Lower Duwamish Waterway sediment

Receptor Population	Media	Contaminant	95 UCL Concentration (ppm)	Exposure Route	Estimated Dose (mg/kg-day)	MRL/RfD (mg/kg-day)	Hazard Quotient
Tribal netfisher	Intertidal and Subtidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	6e-06	3e-04	2e-02
		Cadmium	1.6		4e-07	1e-03	4e-04
		Chlordane	0.014		4e-09	5e-04	8e-06
		PCBs	2.2		2e-06	2e-05	9e-02
		Mercury	0.29		8e-08	1e-04	8e-04
Hazard Index							1e-01
Tribal netfisher (child to adult)	Intertidal and Subtidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	8e-06	3e-04	3e-02
		Cadmium	1.6		1e-06	1e-03	1e-03
		Chlordane	0.014		1e-08	5e-04	2e-05
		PCBs	2.2		4e-06	2e-05	2e-01
		Mercury	0.29		2e-07	1e-04	2e-03
Hazard Index							3e-01
Children playing at Duwamish River Park	Intertidal Sediment	Arsenic	11	Ingestion/ Dermal Contact	2e-05	3e-04	6e-02
		Cadmium	0.4		6e-07	1e-03	6e-04
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.7		1e-06	2e-05	7e-02
		Mercury	0.3		5e-07	1e-04 ^b	5e-03
Hazard Index							1e-01
Children playing at Gateway Park—South	Intertidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	3e-05	3e-04	9e-02
		Cadmium	0.3		5e-07	1e-03	5e-04
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.4		8e-07	2e-05	4e-02
		Mercury	0.2		3e-07	1e-04 ^b	3e-03
Hazard Index							1e-01
Children playing at Gateway Park—North	Intertidal Sediment	Arsenic	12	Ingestion/ Dermal Contact	2e-05	3e-04	7e-02
		Cadmium	0.7		1e-06	1e-03	1e-03
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.5		1e-06	2e-05	5e-02

Table C11. Noncancer hazard calculations for exposure to Lower Duwamish Waterway sediment

Receptor Population	Media	Contaminant	95 UCL Concentration (ppm)	Exposure Route	Estimated Dose (mg/kg-day)	MRL/RfD (mg/kg-day)	Hazard Quotient
		Mercury	0.2		3e-07	1e-04 ^b	3e-03
Hazard Index							1e-01
Children playing along Boeing View Trail	Intertidal Sediment	Arsenic	14	Ingestion/ Dermal Contact	2e-05	3e-04	8e-02
		Cadmium	2		3e-06	1e-03	3e-03
		Chlordane	NA		NA	5e-04	NA
		PCBs	2.6		5e-06	2e-05	3e-01
		Mercury	0.935		1e-06	1e-04 ^b	1e-02
Hazard Index							4e-01
Crabfishers near Terminal 105	Intertidal and Subtidal Sediment	Arsenic	17	Ingestion/ Dermal Contact	7e-06	3e-04	2e-02
		Cadmium	8		3e-06	1e-03	3e-03
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.5		5e-07	2e-05	3e-02
		Mercury	0.5		2e-07	1e-04 ^b	2e-03
Hazard Index							5e-02
Children playing along Herring's House Park	Intertidal Sediment	Arsenic	18	Ingestion/ Dermal Contact	3e-05	3e-04	1e-01
		Cadmium	0.7		1e-06	1e-03	1e-03
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.8		2e-06	2e-05	8e-02
		Mercury	0.2		3e-07	1e-04 ^b	3e-03
Hazard Index							2e-01
Shellfishers at Kellogg Island	Intertidal Sediment	Arsenic	18	Ingestion/ Dermal Contact	8e-06	3e-04	3e-02
		Cadmium	0.8		2e-07	1e-03	2e-04
		Chlordane	NA		NA	5e-04	NA
		PCBs	0.8		8e-07	2e-05	4e-02
		Mercury	0.3		1e-07	1e-04 ^b	1e-03
Hazard Index							7e-02

95 UCL = 95th upper confidence limit on the mean, assuming a normal distribution. Public access scenarios used 95th percentile of intertidal sediment samples located within 1,000 ft of access area

Note—Doses are reported in scientific notation format. For example, 1e-02 is the same as 1 x 10⁻² or 0.01.

Table C12. Cancer risk calculations for exposure to Duwamish River sediment

Receptor Population	Media	Contaminant	95 UCL Concentration (ppm)	Exposure Route	Estimated Dose (mg/kg-day)	Cancer Potency Factor)	Cancer Risk	EPA Cancer Group
Tribal Netfishers	Intertidal and Subtidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	3e-06	1.5	5e-06	A
		Chlordane	0.014		2e-09	0.35	1e-09	B2
		cPAHs	0.61		3e-07	7.3	2e-06	B2
		DDE	0.009		3e-08	0.34	1e-08	B2
		PCBs	2.2		1e-06	2	2e-06	B2
Sum of Cancer Risks							9e-06	
Tribal Netfishers (child to adult)	Intertidal and Subtidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	5e-06	1.5	7e-06	A
		Chlordane	0.014		3e-09	0.35	2e-09	B2
		cPAHs	0.61		3e-07	7.3	2e-06	B2
		DDE	0.009		5e-08	0.34	2e-08	B2
		PCBs	2.2		1e-06	2	3e-06	B2
							1e-05	

95 UCL = 95th upper confidence limit on the mean, assuming a normal distribution.

Note— Cancer risks are reported in scientific notation format. For example, 1e-02 is the same as 1×10^{-2} or 0.01.

Table C12 (cont.). Cancer risk calculations for exposure to Duwamish River sediment

Receptor Population	Media	Contaminant	Maximum Concentration (ppm)	Exposure Route	Estimated Dose (mg/kg-day)	Cancer Potency Factor)	Cancer Risk	EPA Cancer Group
People recreating at Duwamish River Park	Intertidal Sediment	Arsenic	11	Ingestion/ Dermal Contact	1e-06	1.5	2e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	0.2		4e-09	7.3	3e-08	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	0.7		5e-08	2	1e-07	B2
Sum of Risks							2e-06	
People Recreating at Gateway Park—South	Intertidal Sediment	Arsenic	16	Ingestion/ Dermal Contact	2e-06	1.5	3e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	1.21		2e-08	7.3	2e-07	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	0.4		3e-08	2	6e-08	B2
Sum of Cancer Risks							3e-06	
Gateway Park—North	Intertidal Sediment	Arsenic	12	Ingestion/ Dermal Contact	1e-06	1.5	2e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	1.8		2e-07	7.3	1e-06	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	0.5		6e-08	2	1e-07	B2
Sum of Cancer Risks							2e-06	
Boeing View Trail	Intertidal Sediment	Arsenic	15	Ingestion/ Dermal Contact	1e-06	1.5	2e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	2.3		2e-07	7.3	2e-06	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	2.6		3e-07	2	6e-07	B2
Sum of Cancer Risks							5e-06	

Receptor Population	Media	Contaminant	Maximum Concentration (ppm)	Exposure Route	Estimated Dose (mg/kg-day)	Cancer Potency Factor)	Cancer Risk	EPA Cancer Group
Crab fishing near Terminal 105	Intertidal and Subtidal Sediment	Arsenic	17	Ingestion/ Dermal Contact	1e-06	1.5	2e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	1.57		3e-07	7.3	2e-06	B2
		DDE	0.004		NA	0.34	NA	B2
		PCBs	0.5		8e-08	2	2e-07	B2
Sum of Cancer Risks							4e-06	
Children playing near Herring's House Park	Intertidal Sediment	Arsenic	18	Ingestion/ Dermal Contact	2e-06	1.5	3e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	0.27		5e-09	7.3	4e-08	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	0.8		6e-08	2	1e-07	B2
Sum of Cancer Risks							3e-06	
Shellfishers near Kellogg Island	Intertidal Sediment	Arsenic	18	Ingestion/ Dermal Contact	1e-06	1.5	2e-06	A
		Chlordane	NA		NA	0.35	NA	B2
		cPAHs	0.64		1e-07	7.3	7e-07	B2
		DDE	NA		NA	0.34	NA	B2
		PCBs	0.8		1e-07	2	3e-07	B2
Sum of Cancer Risks							3e-06	

95th percentile of intertidal sediment samples located within 1,000 ft of access area

Note—Doses are reported in scientific notation format. For example, 1e-02 is the same as 1 x 10⁻² or 0.01.

Appendix D - Community Interview Questions

1. Do you know people who fish in the river?
2. Have you heard about people eating fish, shellfish, or crab from the Duwamish River?
3. How often do they eat fish from the river? Daily? 2 times a week? Weekly?
4. Do people eat the organs of the fish? The liver? The head?
5. Do you know anyone who has become sick from eating the seafood?
6. Have you heard any stories about fish that look different or unusual from the river?
7. Do you or does anyone in your family have health concerns regarding the Duwamish River?

Appendix E - Public Health Hazard Conclusion Categories

Category	Definition
1. Urgent Public Health Hazard	This category is used for sites where short-term exposures (<1 yr) to hazardous substances or conditions could result in adverse health effects that require rapid intervention.
2. Public Health Hazard	This category is used for sites that pose a public health hazard as a result of the existence of long-term exposures (>1 yr) to hazardous substances or conditions that could result in adverse health effects.
3. Indeterminate Public Health Hazard	This category is used for sites in which “critical” data are insufficient with regard to extent of exposure and/or toxicologic properties at estimated exposure levels.
4. No Apparent Public Health Hazard	The category is used for sites where human exposure to contaminated media may be occurring, may have occurred in the past, and/or may occur in the future, but the exposure is not expected to cause any adverse health effects.
5. No Public Health Hazard	This category is used for sites that, because of the absence of exposure, do NOT pose a public health hazard.

Appendix F: Contaminant Screening Process

The information in this section lays out how the contaminants of concern were chosen from a large set of different contaminants in fish/shellfish and sediment. In general, a contaminant's maximum fish concentration or 95th percentile sediment concentration is compared to a screening value (comparison value), and if the contaminant's concentration is greater than that value, then it is considered further. The health comparison values used in this public health assessment include screening values in fish from EPA guidance, environmental media evaluation guides (EMEGs), cancer risk evaluation guides (CREGs), reference dose media evaluation guides (RMEGs), EPA Region 9 Preliminary Remedial Goals (PRGs), and Model Toxics Control Act (MTCA) cleanup values for soil.

EMEGs are calculated from ATSDR's chronic Minimum Risk Levels (MRLs), using exposure parameters such as ingestion rate and body weight. EMEGs currently exist only for soil, water, and air. The MRL represents an estimate of daily human exposure to a contaminant below which noncancer adverse health effects are unlikely to occur. Comparison values were calculated using chronic Reference Doses (RfDs) for chemicals that did not have chronic MRLs. These values are called Reference Media Evaluation Guide (RMEGs). RfDs represent an estimate of daily human exposure to a contaminant below which non-cancer adverse health effects are unlikely. PRGs and MTCA cleanup values are determined using a similar methodology. Cancer Risk Evaluation Guides (CREGs) are estimated contaminant concentrations based on the probability that 1 additional cancer case may occur in excess of the number that will be expected to occur among 1 million people (assuming they have been exposed to the contaminant for a lifetime).

EPA's "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories" suggests screening values to use when evaluating contaminant data in fish from water bodies where subsistence fishers consume fish. These values are calculated assuming a fish consumption rate of 142.4 g/day, a body weight of 70 kg, and a 70 year lifetime. Values were calculated using the most current oral RfD's and cancer potency factors in EPA's IRIS database. For contaminants that did not have recommended screening values listed by EPA, a similar methodology was used to derive screening values using MRLs and RfDs and CSFs (see equations below). This screening method ensured consideration of contaminants that may be of concern for fish consumers, especially higher consumption groups such as tribal and API populations. The equations below show how comparison values were calculated for both noncancer and cancer endpoints associated with consumption of fish. A complete list of contaminants in fish/shellfish and sediment and their respective comparison values are provided in this Appendix.

$$CV_{\text{cancer}} = \frac{10^{-5} * BW}{CPF * FIR * CF}$$

$$CV_{\text{non-cancer}} = \frac{RfD \text{ or } MRL * BW}{FIR * CF}$$

Table F1. Parameters used to calculate comparison values used in the fish contaminant screening process. Lower Duwamish Waterway, Seattle, King County, Washington

Abbreviation	Parameter	Units	Value	Comments
CV	Comparison Value	mg/kg	Calculated	
RfD	Reference Dose	mg/kg-day	Chemical Specific	EPA
MRL	Minimal Risk Level	mg/kg-day	Chemical Specific	ATSDR
BW	Body Weight	kg	60	Female body weight
FIR	Fish Ingestion Rate	g/day	142.4	EPA
CF	Conversion Factor	kg/g	0.001	kilograms per gram
CPF	Cancer Potency Factor	kg-day/mg	Chemical Specific	EPA

Figure F1 - Insert Fish screen flow chart here

Figure F2 - insert sediment Screening Flow chart

Table F2. Frequency of detection for contaminants with screening values in Lower Duwamish Waterway Fish, Seattle, Washington

Frequency of detection for contaminants with screening values in Lower Duwamish Waterway Fish, Seattle, Washington								
	Frequency Detected : Number of Analyses							
Contaminant	Coho	Chinook	English Sole	Mussels	Striped Perch	Dungeness Crab	Rock Crab	Quillback Rockfish
1,2,4-Trichlorobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
1,2-Dichlorobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
1,2-Diphenylhydrazine	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
1,4-Dichlorobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4,5-Trichlorophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4,6-Trichlorophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4-Dichlorophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4-Dimethylphenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4-Dinitrophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,4-Dinitrotoluene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2,6-Dinitrotoluene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2-Chloronaphthalene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2-Chlorophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
3,3'-Dichlorobenzidine	0:0	0:0	0:3	0:62	0:0	0:2	0:0	0:0
4,4'-DDD	40:70	79:83	9:9	0:27	0:0	0:0	0:0	0:9
4,4'-DDE	70:70	83:83	7:9	0:27	0:0	0:0	0:0	0:1
4,4'-DDT	7:68	55:83	0:9	0:27	0:0	0:0	0:0	2:6
4,6-Dinitro-o-cresol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Chloroaniline	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Acenaphthene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Aldrin	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Aniline	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Anthracene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Antimony	0:0	0:0	0:3	0:62	0:0	0:2	0:0	0:0
Aroclor-1254	47:47	72:72	30:30	33:60	11:11	3:3	9:9	5:5
Arsenic	18:18	18:18	9:9	63:63	0:0	2:2	0:0	0:0
Benzidine	0:0	0:0	0:3	0:62	0:0	0:2	0:0	0:0
Benzo(a)pyrene TEQ	0:16	0:19	0:6	31:62	0:0	0:2	0:0	0:0
Benzo(a)pyrene	0:16	0:19	0:6	0:62	0:0	0:2	0:0	0:0

Frequency of detection for contaminants with screening values in Lower Duwamish Waterway Fish, Seattle, Washington								
	Frequency Detected : Number of Analyses							
Contaminant	Coho	Chinook	English Sole	Mussels	Striped Perch	Dungeness Crab	Rock Crab	Quillback Rockfish
Benz(a)anthracene	0:16	0:19	0:6	27:62	0:0	0:2	0:0	0:0
Benzo(b)fluoranthene	0:16	0:19	0:6	9:62	0:0	0:2	0:0	0:0
Benzo(k)fluoranthene	0:16	0:19	0:6	0:62	0:0	0:2	0:0	0:0
Chrysene	0:16	0:19	0:6	30:62	0:0	0:2	0:0	0:0
Dibenz(a,h)anthracene	0:16	0:19	0:6	0:62	0:0	0:2	0:0	0:0
Indeno[1,2,3-cd]pyrene	0:16	0:19	0:6	0:62	0:0	0:2	0:0	0:0
Benzoic acid	1:18	0:18	0:6	62:62	0:0	0:2	0:0	0:0
beta-hexachlorocyclohexane	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
bis(2-chloroethyl)ether	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
bis(2-ethylhexyl)phthalate	4:18	4:18	1:6	2:62	0:0	0:2	0:0	0:0
bis-chloroisopropyl ether	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Butyl benzyl phthalate	0:0	0:0	0:6	0:62	0:0	0:2	0:0	0:0
Cadmium	0:0	0:0	0:3	63:63	0:0	2:2	0:0	0:0
Carbazole	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
alpha Chlordane	24:57	50:83	3:9	0:0	0:0	0:0	0:0	0:0
gamma-Chlordane	8:57	15:83	1:9	0:0	0:0	0:0	0:0	0:0
Chlordane	0:0	0:0	0:0	0:27	0:0	0:0	0:0	0:0
Chromium	0:0	0:0	2:3	59:63	0:0	2:2	0:0	0:0
Dieldrin	4:57	6:83	0:9	0:27	0:0	0:0	0:0	0:0
Diethyl phthalate	0:18	0:18	0:6	0:62	0:0	0:0	0:0	0:0
Di--butyl phthalate	0:18	0:18	1:6	0:62	0:0	0:0	0:0	0:0
Di--octyl phthalate	0:18	0:18	0:6	0:62	0:0	0:0	0:0	0:0
Endosulfan sulfate	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Endrin	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Fluoranthene	0:18	0:18	0:6	30:62	0:0	0:2	0:0	0:0
Fluorene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
gamma-hexachlorocyclohexane	0:57	1:83	0:9	0:27	0:0	0:0	0:0	0:0
Heptachlor	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Heptachlor epoxide	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Hexachlorobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:9
Hexachlorobutadiene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0

Frequency of detection for contaminants with screening values in Lower Duwamish Waterway Fish, Seattle, Washington								
	Frequency Detected : Number of Analyses							
Contaminant	Coho	Chinook	English Sole	Mussels	Striped Perch	Dungeness Crab	Rock Crab	Quillback Rockfish
Hexachlorocyclopentadiene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Hexachloroethane	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Isophorone	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Methoxychlor	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Methylmercury	16:16	19:19	33:33	62:62	5:11	3:3	8:9	8:8
Naphthalene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Nitrobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
–Nitrosodimethylamine	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
–Nitroso-di–propylamine	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
–Nitrosodiphenylamine	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
PCBs (total-calc'd)	45:55	72:83	30:30	60:60	11:11	3:3	9:9	5:5
Pentachlorophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Phenol	0:18	0:18	0:6	0:63	0:0	0:2	0:0	0:0
Pyrene	0:18	0:18	0:6	26:62	0:0	0:2	0:0	0:0
Toxaphene	0:57	0:83	0:9	0:27	0:0	0:2	0:0	0:0
Tributyltin	0:0	0:0	7:24	60:60	11:11	2:3	0:9	0:0

Table F3. Frequency of detection for contaminants **without** screening values in Lower Duwamish Waterway Fish, Seattle, Washington

Frequency of detection for contaminants without screening values in Lower Duwamish Waterway Fish, Seattle, Washington								
	Frequency Detected: Number of Analyses							
Contaminant	Coho	Chinook	English Sole	mussels	perch	Dungeness	Rock Crab	Rockfish
1,3-Dichlorobenzene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2-Methylnaphthalene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2-Methylphenol	0:18	0:18	0:6	53:62	0:0	0:2	0:0	0:0
2-Nitroaniline	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
2-Nitrophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
3-Nitroaniline	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Bromophenyl phenyl ether	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Chloro-3-methylphenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Chlorophenyl phenyl ether	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Methylphenol	0:18	0:18	0:6	2:62	0:0	0:2	0:0	0:0
4-Nitroaniline	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
4-Nitrophenol	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Acenaphthylene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
alpha-hexachlorocyclohexane	6:57	6:83	0:9	0:27	0:0	0:0	0:0	0:0
alpha-Endosulfan	0:57	0:83	0:9	0:27	0:0	0:2	0:0	0:0
Aroclor-1016	0:57	0:83	0:9	0:62	0:0	0:2	0:0	0:5
Aroclor-1016/1242	0:0	0:0	3:3	0:0	8:11	1:1	9:9	0:0
Aroclor-1221	0:57	0:83	0:9	0:62	0:0	0:2	0:0	0:5
Aroclor-1232	0:57	0:83	0:9	0:62	0:0	0:2	0:0	0:5
Aroclor-1242	0:57	0:83	0:9	0:62	0:0	0:2	0:0	0:5
Aroclor-1248	0:57	0:83	7:30	0:62	0:11	1:3	0:9	0:5
Aroclor-1260	42:47	71:72	30:30	0:62	11:11	3:3	9:9	5:5
Benzo(g,h,i)perylene	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Benzyl alcohol	0:18	0:18	0:6	6:62	0:0	0:2	0:0	0:0
beta-Endosulfan	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
bis(2-chloroethoxy)methane	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Cobalt	0:0	0:0	0:0	29:29	0:0	0:0	0:0	0:0
Copper	18:18	18:18	9:9	62:62	0:0	2:2	0:0	0:0
Coprostanol	0:6	0:6	0:6	0:62	0:0	0:2	0:0	0:0
delta-hexachlorocyclohexane	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0

Frequency of detection for contaminants without screening values in Lower Duwamish Waterway Fish, Seattle, Washington								
	Frequency Detected: Number of Analyses							
Contaminant	Coho	Chinook	English Sole	mussels	perch	Dungeness	Rock Crab	Rockfish
Dibenzofuran	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Dibutyltin	0:0	0:0	0:0	0:28	0:0	0:0	0:0	0:0
Dimethyl phthalate	0:18	0:18	0:6	0:62	0:0	0:2	0:0	0:0
Endrin aldehyde	0:57	0:83	0:9	0:27	0:0	0:0	0:0	0:0
Lead	1:18	0:18	0:9	62:62	0:0	2:2	0:0	0:0
Molybdenum	0:0	0:0	0:0	25:25	0:0	0:0	0:0	0:0
Monobutyltin	0:0	0:0	0:0	18:28	0:0	0:0	0:0	0:0
Nickel	0:0	0:0	0:3	62:62	0:0	2:2	0:0	0:0
Phenanthrene	0:18	0:18	0:6	13:62	0:0	0:2	0:0	0:0
Silver	0:0	0:0	0:3	7:62	0:0	2:2	0:0	0:0
Vanadium	0:0	0:0	0:0	18:18	0:0	0:0	0:0	0:0
Zinc	0:0	0:0	3:3	62:62	0:0	2:2	0:0	0:0

Table F4. Selection of contaminants of concern in Lower Duwamish Waterway Fish, Seattle, Washington

Contaminant	Maximum								Comparison Value ^b	COC?
	Chinook Salmon	Coho Salmon	English Sole	Quillback Rockfish	Red Rock Crab	Dungeness Crab ^a	Perch ^c	mussels		
Arsenic (mg/kg)	1.4	1.6	15	NA	NA	12.5	1.4	1.1	0.003	Yes
Benzoic Acid (mg/kg)	<0.3	0.65	<0.1	NA	NA	<0.1	NA	12	1900	No
Bis(2ethylhexyl)phthalate (ug/kg)	5350	4750	<0.1	NA	NA	<16	NA	0.2	351	Explain
Cadmium (mg/kg)	NA	NA	<0.05	NA	NA	<0.02	NA	0.7	0.5	Yes
Chlordane (ug/kg)	15.4	2.5	3.4	NA	NA	NA	NA	<7	14	Yes
Chromium (mg/kg)	NA	NA	0.16	NA	NA	<0.2	NA	0.2	1.5	No
cPAHs (ug/kg)	<46	<43	<31	NA	NA	<29	NA	40	0.7	Yes
Di- – butyl phthalate (ug/kg)	<50	<50	56	NA	NA	NA	NA	59	49000	No
DDD (ug/kg)	4.8	3.2	4.7	<0.1	NA	NA	NA	<1.3	20	No
DDE (ug/kg)	33.8	17.4	5.3	<0.1	NA	NA	NA	<1.3	14	Yes
DDT (ug/kg)	2.7	<2	<2	<0.1	NA	NA	NA	<1.3	14	No
Fluoranthene (ug/kg)	<20	<20	<24	NA	NA	<16	NA	123	19600	No
PCBs (ug/kg)	160	97	640	428	204	177	228	73	2	Yes
Pyrene (ug/kg)	<50	<50	<24	NA	NA	<16	NA	122	14000	No
Mercury (ug/kg)	150	52	83	567	130	111	60	16	49	Yes
Tributyltin (ug/kg)	NA	NA	50	NA	<2	82	25	93	147	No

Table F5. Frequency of detection for contaminants **with** screening values and selection of contaminants of concern in Lower Duwamish Waterway sediment Seattle, Washington

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
1,1,1,2-Tetrachloroethane	0:47				No
1,1,1-Trichloroethane	0:61				No
1,1,2,2-Tetrachloroethane	0:61				No
1,1,2-Trichloroethane	0:61				No
1,1,2-Trichlorotrifluoroethane	0:59				No
1,1-Dichloroethane	0:61				No
1,1-Dichloroethene	0:61				No
1,1-Dichloropropanone	0:45				No
1,1-Dichloropropene	0:47				No
1,2,3-Trichlorobenzene	0:47				No
1,2,3-Trichloropropane	0:47				No
1,2,4-Trichlorobenzene	23:807	0.110	500	RMEG	No
1,2-Dibromo-3-chloropropane	0:47				No
1,2-Dichlorobenzene	75:801	0.110	5000	RMEG	No
1,2-Dichloroethane	0:61				No
1,2-Dichloroethene	0:2				No
1,2-Dichloropropane	0:61				No
1,2-Diphenylhydrazine	1:216	0.120	0.9	CREG	No
1,3-Dichlorobenzene	25:788	0.110	16	Region 9	No
1,3-Dichloropropane	0:47				No
1,3,4-Trimethylbenzene	2:47	0.004	NA	NA	No
1,3,5-Trimethylbenzene	1:47	0.004	21	Region 9	No
1,4-Dichlorobenzene	151:804	0.130	41.7	MTCA	No
1-Chlorobutane	0:47				No
1-Methylnaphthalene	3:3	0.041	4000	EMEG	No
2-Chloroethylvinyl ether	0:12				No
2,2-Dichloropropane	0:47				No
2,4,5-Trichlorophenol	1:734	0.590	5000	RMEG	No
2,4,6-Trichlorophenol	1:734	0.577	60	CREG	No
2,4-Dichlorophenol	1:734	0.340	200	RMEG	No

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
2,4-Dimethylphenol	8:779	0.331	1000	RMEG	No
2,4-Dinitrophenol	2:726	1.100	100	RMEG	No
2,4-Dinitrotoluene	1:734	0.564	100	EMEG	No
2,6-Dinitrotoluene	1:734	0.564	80	MTCA	No
2-Chloronaphthalene	1:734	0.110	4000	RMEG	No
2-Chlorophenol	1:734	0.120	300	RMEG	No
2-Chlorotoluene	0:47				No
2-Hexanone	0:61				No
2-Methylnaphthalene	117:811	0.130	NA	NA	No
2-Methylphenol	10:811	0.220	3100	Region 9	No
2-Nitroaniline	1:726	0.590	1.7	Region 9	No
2-Nitrophenol	1:734	0.570	NA	NA	No
2,4'-DDD	0:3				No
2,4'-DDE	0:3				No
2,4'-DDT	0:3				No
2-Nitropropane	0:47				No
3-Nitroaniline	0:688				No
3,3'-Dichlorobenzidine	2:668	0.590	2	CREG	No
4-Bromophenyl phenyl ether	1:734	0.120	NA	NA	No
4-Chloro-3-methylphenol	1:726	0.240	NA	NA	No
4,4'-DDD	20:219	0.020	3	CREG	No
4,4'-DDE	40:219	0.012	2	CREG	No
4,4'-DDT	16:219	0.020	2	CREG	No
4-Chloroaniline	3:649	0.356	200	RMEG	No
4-Chlorophenyl phenyl ether	1:734	0.120	NA	NA	No
4-Chlorotoluene	0:47				No
4-Methylphenol	50:473	0.400	310	Region 9	No
4-Nitroaniline	2:672	0.590	NA	NA	No
4-Nitrophenol	1:726	0.570	NA	NA	No
Acenaphthene	317:811	0.255	3000	RMEG	No
Acenaphthylene	82:811	0.110	NA	NA	No
Acetone	5:61	0.162	5000	RMEG	No

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
Aldrin	2:215	0.005	2	RMEG	No
Allyl Chloride	0:47				No
Aluminum	684:691	29000	76000	Region 9	No
Ammonia	81:81	74	20000	Int. EMEG	No
Aniline	2:126	0.110	100	RMEG	No
Anthracene	560:812	0.420	20000	RMEG	No
Antimony	163:647	13	20	RMEG	No
Aroclor-1016	3:984	0.080	4	RMEG	No
Aroclor-1221	2:781	0.054	0.220	Region 9	No
Aroclor-1232	2:781	0.030	0.220	Region 9	No
Aroclor-1242	136:984	0.319	0.220	Region 9	Total PCBs
Aroclor-1248	208:983	0.869	0.220	Region 9	Total PCBs
Aroclor-1254	731:987	1.800	1	EMEG	Total PCBs
Aroclor-1260	745:986	2.400	0.220	Region 9	Total PCBs
Arsenic	789:887	30	20	EMEG	Yes
Barium	609:609	153	4000	RMEG	No
Benzene	1:61	0.006	10	CREG	No
Benzidine	2:16	1.350	0.003	CREG	Too Few
Benzo(a)anthracene + Chrysene	735:813	1.100	0.137	MTCA	cPAHs
Benzo(a)pyrene	719:812	1.045	0.100	CREG	cPAHs
Benzo(b)fluoranthene	701:784	1.600	0.137	MTCA	cPAHs
Benzo(g,h,i)perylene	684:812	0.570	NA	NA	No
Benzo(k)fluoranthene	674:784	0.910	0.137	MTCA	cPAHs
Benzoic acid	71:786	1.100	200000	RMEG	No
Benzyl alcohol	14:799	0.511	24000	MTCA	No
Beryllium	672:708	0.6	50	EMEG	No
Biphenyl	2:2	0.030	3000	RMEG	No
bis(2-chloroethyl)ether	0:734				No
bis(2-chloroisopropyl)ether	0:734				No
Bis(2-chloroethoxy) methane	2:734	0.120	NA	NA	No
bis(2-ethylhexyl)phthalate	701:820	4.010	71.4	MTCA	No
Bromobenzene	0:47				No

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
Bromochloromethane	0:47				No
Bromodichloromethane	0:61				No
Bromoform	0:61				No
Bromomethane	0:61				No
Butyl benzyl phthalate	437:818	0.360	10000	RMEG	No
Cadmium	617:869	4	10	EMEG	No
Carbazole	377:734	0.320	50	MTCA	No
Carbon disulfide	18:61	0.018	5000	RMEG	No
Carbon tetrachloride	0:61				No
Chlordane	12:126	0.040	2	CREG	No
alpha-Chlordane	1:89	0.025			No
trans-Chlordane	4:85	0.025			No
Chlorobenzene	0:61				No
Chloroethane	0:61				No
Chloroform	1:61	0.006	500	EMEG	No
Chloromethane	0:61				No
Chromium	830:845	70	210	Region 9	No
Chromium VI	1:20	15	200	RMEG	No
Chrysene	759:813	1.540	0.137	MTCA	cPAHs
cis-1,2-Dichloroethene	1:59	0.004	NA	NA	No
cis-1,3-Dichloropropene	0:61				No
Cobalt	459:474	14	4700	Region 9	No
Copper	876:887	147	2960	MTCA	No
Coprostanol	84:227	2.4	NA	NA	No
Cyanide	1:25	49	1000	RMEG	No
Cymene	3:47	0.004	NA	NA	No
Dibenzo(a,h)anthracene	413:812	0.205	0.137	MTCA	cPAHs
Dibenzofuran	240:810	0.150	290	Region 9	No
Dibromochloromethane	0:61				No
Dibutyltin	88:139	0.051	NA	NA	No
Dichloromethane	1:61	0.020	NA	NA	No
Dichlorodifluoromethane	0:9				No

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
Dieldrin	21:215	0.010	0.04	CREG	No
Diethyl ether	0:47				No
Diethyl phthalate	9:818	0.120	40000	RMEG	No
Dimethyl phthalate	132:818	0.120	80000	MTCA	No
Di--butyl phthalate	251:818	0.282	5000	RMEG	No
Di--octyl phthalate	50:819	0.130	20000	int EMEG	No
Dioxin/furan TCDD toxicity equivalent	29:29	0.0001	0.00005	EMEG	Explain
Endosulfan	0:92				No
Endosulfan sulfate	2:158	0.010			No
Endrin	0:175				No
Endrin aldehyde	5:158	0.020	NA	NA	No
Endrin ketone	2:85	0.020	NA	NA	No
Ethyl Methacrylate	0:47				No
Ethylbenzene	1:95	0.009	5000	RMEG	No
Ethylene bromide	0:47				No
Fluoranthene	778:813	2.900	2000	RMEG	No
Fluorene	389:811	0.245	2000	RMEG	No
Gasoline	0:24				No
Heavy oil	5:13	4580	200	MTCA	Explain
Heptachlor	4:214	0.005	0.200	CREG	No
Heptachlor epoxide	3:176	0.006	0.08	CREG	No
Hexachlorobenzene	50:806	0.110	0.4	CREG	No
Hexachlorobutadiene	1:811	0.220	9	CREG	No
alpha-Hexachlorocyclohexane	0:175				No
beta-Hexachlorocyclohexane	1:175	0.005	0.4	CREG	No
delta-Hexachlorocyclohexane	1:95	0.004	NA	NA	No
gamma-BHC	5:210	0.005	20	RMEG	No
Hexachlorocyclopentadiene	2:618	0.590	300	RMEG	No
Hexachloroethane	1:793	0.220	50	CREG	No
Indeno(1,2,3-cd)pyrene	688:813	0.620	0.137	MTCA	cPAHs
Iron	689:689	39520	23000	Region 9	Explain

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
Isophorone	0:733				No
Isopropylbenzene	0:47				No
Lead	876:887	260	400	Region 9	No
Magnesium	636:636	9800	NA	NA	No
Manganese	652:652	619	3000	Region 9	No
Mercury	748:875	0.6	24	MTCA	Fish Pathway
Methacrylonitrile	47:47	0.018	5	RMEG	No
Methoxychlor	6:175	0.016	300	RMEG	No
Methyl Acrylate	0:47				No
Methyl ethyl ketone	18:61	0.024	48000	MTCA	No
Methyl-t-butyl ether	0:47				No
Methyl iodide	0:47				No
Methyl methacrylate	0:47				No
Methylmercury	59:59	0.002	5	RMEG	No
Methylene bromide	0:47				No
Mirex	0:3				No
Molybdenum	37:156	6	300	RMEG	No
Naphthalene	129:811	0.130	1000	RMEG	No
Nickel	856:873	37	1000	RMEG	No
Nitrobenzene	0:734				No
–Nitrosodimethylamine	0:216				No
–Nitroso-di–propylamine	0:734				No
–Nitrosodiphenylamine	20:811	0.120	100	CREG	No
Octadecanal	2:2	1.1	NA	NA	No
Pentachloroethane	0:47				No
Pentachlorophenol	13:759	0.590	6	CREG	No
Phenanthrene	741:813	1.5	NA	NA	No
Phenol	229:811	0.300	30000	RMEG	No
Polychlorinated Biphenyl Dioxin-like Congeners		0.00009	0.000007	MTCA	Explain
PCB 77	20:662				
PCB 81	0:333				

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
PCB 105	470:657				
PCB 114	9:333				
PCB 118	582:661				
PCB 123	0:333				
PCB 126	16:661				
PCB 156	253:659				
PCB 157	76:657				
PCB 167	56:333				
PCB 169	0:659				
PCB 189	30:659				
Propylbenzene	0:47				No
Pyrene	768:813	2.600	2000	RMEG	No
Selenium	303:697	20	300	EMEG	No
Silver	586:869	2	300	RMEG	No
Styrene	0:61				No
Tetrabutyltin	11:153	0.020	NA	NA	No
Tetrachloroethene	3:90	0.009	19.6	MTCA	No
Thallium	355:707	36	5.2	Region 9	Explain
Tin	229:351	15	48000	MTCA	No
Toluene	6:61	0.006	10000	RMEG	No
Total Petroleum Hydrocarbons	65:73	4300			
Total Polynuclear Aromatic Hydrocarbons	599:613	16	NA	NA	No
Total Polychlorinated Biphenyls	1194:1325	4.446	0.4	CREG	Yes
Total Tetrachlorodibenzo-p-dioxins	23:30	0.00002	0.000007	MTCA	Explain
Total of 6 isomers: pp,op-DDT,-DDD,-DDE	83:213	0.080	NA	NA	No
Toxaphene	0:175				No
TPH - Diesel	6:31	1415	200	MTCA	Explain
TPH - Gasoline Range	0:8				No
TPH - Heavy Fuel Oil Range	2:8	328	200	MTCA	Too Few
Tributyltin	130:154	0.312	20	RMEG	Fish Pathway
Trichloroethene	4:95	0.010	91	MTCA	No

Frequency of detection for contaminants with screening values in LDW sediment					
Frequency detected : Frequency analyzed					
	count	95 th % (ppm)	Comparison Value (ppm)	Source	Contaminant of Concern?
Trichlorofluoromethane	0:59				No
Vanadium	474:474	81	560	MTCA	No
Vinyl acetate	0:12				No
Vinyl chloride	0:61				No
Ortho-xylene	1:56	0.004	10000	int EMEG	No
Total xylenes	0:43				No
m,p-Xylene	1:56	1	10000	int EMEG	No
Zinc	872:886	360	20000	EMEG	No

Screening rationale

Generally speaking, contaminants that exceeded screening criterion were considered to be of concern and were evaluated further. In some cases, contaminants exceeded screening criterion but were not considered as contaminants of concern for other reasons. These explanations are listed below.

Background levels

Iron was found in sediment at levels that exceeded the Region 9 PRG. This level, however, is well within the background range of iron that occurs naturally in the Puget Sound region soils. The 95th percentile of iron found in LDW sediments (39,520 ppm) is much lower than the 90th percentile of background in the Puget Sound region (58,700 ppm).

Toxicological Reasons

Thallium was found in sediment at levels that exceeded the Region 9 PRG. The reference dose used to calculate the PRG is based on thallium sulfate, and the critical effect for that chemical is alopecia (hair loss) in female rats. This endpoint is weak, and therefore, thallium in sediment is not considered to be of great concern.

Bis(2-ethylhexyl)phthalate (DEHP) was found in coho and chinook salmon at levels that exceeded a calculated comparison value. DEHP is a chemical for which there appears to be a threshold for carcinogenicity. In other words, there is a dose of DEHP below which there is no cancer risk, but above which there is some cancer risk. The evidence for this threshold comes from studies of rats and mice dosed with DEHP. Liver cancer in these animals is thought to result from the process of peroxisome proliferation after exposure to DEHP. Without peroxisome proliferation, there were no signs of carcinogenicity. Studies determined a NOEL for peroxisome proliferation at 20 mg/kg/day in mice. Furthermore, rats and mice are considered to be especially sensitive to peroxisome proliferation, compared to humans and other primates. Based on this information, a margin of exposure (MOE) of 10 was determined to be protective for potential risks to humans from DEHP exposure.^f For comparison purposes, a dose calculation for a subsistence consumer of chinook is shown below because the highest level of DEHP in LDW tissue was found in a chinook sample .

DEHP dose = C x IR

Concentration [C] - 5.4 mg/kg

Fish Ingestion Rate (IR) - 0.00058 kg fish / kg body weight /day

DEHP dose = 5.4 mg/kg * 0.00058 kg fish / kg body weight /day

^fDoull J, Cattley R, Elcombe C, Lake BG, Swenberg J, Wilkinson C, Williams G, van Gemert M. A cancer risk assessment of di(2-ethylhexyl)phthalate: Application of the new U.S. EPA Risk Assessment Guidelines. Regul Toxicol Pharmacol 1999; 29: 327-357.

$$= 0.003 \text{ mg/kg/day}$$

This dose can be used in conjunction with the observed NOAEL from the mice study to determine a margin of exposure (MOE) for this consumption scenario.

$$\begin{aligned}\text{Margin of Exposure} &= \text{NOAEL} / \text{Dose} \\ &= 20 \text{ mg/kg/day} / 0.003 \text{ mg/kg/day} \\ &= 6,700\end{aligned}$$

An MOE of 10 was determined to be protective of human health with regard to DEHP exposure, and an MOE of 6,700 was obtained by use of a reasonable conservative exposure scenario. In other words, the exposure scenario resulted in an MOE that was more than 3 orders of magnitude more protective than an MOE that is considered to be protective. For this reason, DEHP was not considered a contaminant of concern.

Too few samples

Although there were data for more than 1,000 sediment samples from the LDW, many chemicals were analyzed infrequently. Among them were some chemicals that may have been detected in a few samples, but in too few samples with which to conduct a worthwhile assessment over a wide area. The lack of complete data is a great source of uncertainty. The contaminants below met initial screening requirements but were not evaluated because of the low number of samples. In general, fewer than 50 samples over the entire waterway was considered to be a paucity.

Benzidine—detected in 2 of 16 sediment samples.

Total Petroleum Hydrocarbons (diesel range)—detected in 6 of 31 samples.

Total Petroleum Hydrocarbons (gasoline range)—detected in 2 of 8 samples.

Heavy Oil—detected in 5 of 13 samples.

Total TCDD—detected in 29 of 29 samples.

Appendix G—Response to public comments

The draft public health assessment was released for comment on July 11, 2002. The public was given an opportunity to provide comments to DOH, and attempts were made to address all of them. Some comments were addressed by simply amending the text within the document, while other comments are responded to below.

1. The contaminant screening process in the draft public health assessment is difficult to follow.

Efforts were made to make the screening process more transparent. Appendix F shows the contaminant screening process.

2. There seem to be discrepancies with the conclusions of the Public Health Assessment and the Remedial Investigation conducted by the LDWG. For example, the RI concluded that arsenic, cPAHs, and PCBs were the largest contributors to risk, in that order, and the PHA states that the main contaminants of concern are PCBs and mercury. Please explain these discrepancies.

The health assessment and the Remedial Investigation each use similar methods in assessing risk or hazards associated with the LDW site. However, there are some different assumptions and approaches made in each document because the purposes of the Remedial Investigation and the public health assessment are different. The RI is designed to support site-specific decisions on the need for cleanup and remediation. The health assessment is more qualitative, designed to determine the relative hazard associated with the site and the need for any recommendations to reduce exposure.

Using cPAHs as an example, the remedial investigation presented relatively high cancer risks associated with consumption of LDW fish contaminated with cPAHs; however, no finfish or crabs had detected levels of cPAHs in their tissues. The cancer risks presented in the RI were based on assumptions that the fish contained $\frac{1}{2}$ of the limit of detection. While this is a sound approach for determining potential data gaps for the baseline risk assessment (i.e., necessary to get detection lower detection limits for cPAH levels in finfish), no reliable conclusion could be made regarding health hazards from such a data set.

PCBs, on the other hand, were detected in all fish species. Hazard quotients associated with PCB exposure ranked highest in all the fish exposure scenarios. This resulted in a fish advisory for the general population based on immune effects of PCBs and for pregnant women or those considering pregnancy based on the combined developmental effects of PCBs, mercury, and DDE.

3. Crab consumption should be included as a completed pathway of exposure based on reports from WDFW of observations of people harvesting crabs from the LDW. Furthermore, LDW crab consumption would clearly result in elevated health risks even further compounded by the consumption habits of LDW API consumers. The elevated risk needs to be recognized and clearly stated.

DOH recognizes that crabs are being caught from the LDW (although we do not know how many or how often) and has considered the crab consumption pathway as a completed pathway of exposure in the final version of the PHA. DOH also recognizes that, according to sparse data, consumption of Dungeness crab might result in an elevated health risk, but only three individual Dungeness crab samples are used to

calculate risk and hazard associated with the consumption of this species. Red rock crab samples are more numerous, and they also contained PCB and mercury levels; therefore, crab consumption limits are included in the recommendation section of this document. We also recognize that API consumers might eat the entire crab. Data from Elliot bay and other studies indicate that the hepatopancreas in crabs tends to accumulate contaminants. Therefore, the PHA recommends that this organ not be eaten.

4. The PHA reported risks for exposure from direct contact to sediment in the 10^{-6} range, which, according to DOH's classification system, would indicate a slight increase in cancer risk. Yet, DOH concludes that "exposure to sediments in the LDW represents no apparent public health hazard."

All sediment exposure scenarios resulted in doses that were well below noncancer reference doses, an indication that exposure to LDW sediments is not expected to result in adverse noncancer health effects. Cancer risk attributable to direct contact with LDW sediments is lower than 1×10^{-5} . Exposure to carcinogenic chemicals at any level will result in some theoretical risk if it is assumed that there is no threshold. Regulatory decisions are usually made when a risk of cancer exceeds a probability of 1×10^{-6} to 1×10^{-4} . The purpose of this health assessment is not to establish cleanup levels in sediment, but to inform people of their potential risks.

5. The text states that DOH advises against harvesting shellfish from King County, "except for Vashon/Maury Island." As DOH is aware, serious health concerns related to arsenic contamination exist on Vashon/Maury Island. In light of this, DOH should update its advisory to include the Vashon/Maury Island shoreline.

Vashon/Maury Island is outside the scope of this document. However, the DOH Office of Food Protection and Shellfish Programs has not found higher levels of arsenic in shellfish from King County or Vashon Island compared to other parts of Puget Sound. In fact, the arsenic levels found have been very consistent throughout Puget Sound, regardless of whether the shellfish tested came from pristine areas or urbanized areas (or areas downwind of Asarco). Advice from DOH against harvesting shellfish from King County's urbanized east shore beaches is based primarily on microbial contamination concerns.

6. WA DOH lists the EMEG Comparison Value of 20 ppm for arsenic in soil. Washington State is well aware that this is not a protective value for arsenic. WA DOH should consult with the Washington State Department of Ecology (Ecology) and others regarding appropriate human health protective levels for arsenic. Ecology records indicate that 0.67 ppm has been determined to be protective.

Ecology has established 20 ppm as the cleanup level for arsenic in residential soil. The cleanup levels is based on an upper-bound of background concentrations in Washington State. Ecology does acknowledge that 0.67 ppm would be protective based on a 10^{-6} increased cancer risk, but that level is well below naturally occurring levels in soil.

7. The PHA states that "factors such as background exposure are considered when formulating conclusions." Yet nowhere in the document are existing body burdens of chemicals presented, discussed, or apparently considered in determining health effects. Please present information on existing body burdens of chemicals such as lead, mercury, PCBs, arsenic, and others and explain how these pre-existing body burdens are taken into account when determining the impacts of sediment exposure and consumption of Duwamish River fish.

Generally, the PHA attempts to determine the risk for adverse health effects that would occur as a result of exposure at a site. These risks often need to be put into perspective by comparing them to risks that we receive as part of our daily lives. An example of this can be seen in fish contaminant levels. PCB levels are higher in LDW English sole compared to English sole in nonurban areas of Puget Sound, but mercury levels are similar. This indicates that risk associated with PCBs is more of a site-related problem (even though PCBs are found in all fish), whereas risk associated with mercury reflects regional conditions. Cleanup of the Duwamish River will have a future impact on PCB levels in resident fish, but it may not have a huge impact with regard to mercury levels.

8. Are there no existing data on toxicological mixtures for chemicals found in the Duwamish River, at recorded levels? At a minimum, known synergistic effects for chemicals present in the river should be presented, with a discussion of any uncertainties associated with reaching conclusions in specific field circumstances.

ATSDR's Division of Toxicology recently prepared a draft interaction profile for persistent chemicals found in fish. The weight-of-evidence analyses of available data on the joint toxic action of mixtures of these components indicate that scientific evidence for greater-than-additive or less-than-additive interactions among these components is limited and inadequate for characterizing the possible modes of joint action on most of the pertinent toxicity targets. Therefore, it is recommended that additivity be assumed as public health protective when assessing exposure to mixtures of these contaminants.

9. The PHA states that “little difference exists between contaminant levels in salmon caught from the LDW versus other areas of Puget Sound.” Yet, Table 7 appears to contradict this statement, especially for Aroclor-1254 levels in coho. Please present the results of a statistical analysis that would help to explain this discrepancy.

A recent statistical analysis performed by the WDFW at the request of DOH compared PCB levels in Duwamish River coho with those from nonurban basins in Puget Sound. The analysis took into consideration several factors, such as lipid content, whether the fish were hatchery reared or wild, gender, and size. While PCB levels in Duwamish coho were significantly higher than those from the Nooksack and Skagit rivers, they were not significantly different than those from the Nisqually or Deschutes rivers. This result supports the notion that the difference in the level of PCBs in the south Puget Sound is at least in part related to the amount of time coho spend feeding in Puget Sound.

10. The PHA states that in the case of average consumers, salmon consumption from the LDW is not expected to pose a risk for any noncancer health effects, and for high-end consumers the PHA states that the doses are still well below actual toxic effects (because of safety factors applied). Given the potential risks indicated by use of approved methodologies, advising the public to disregard the potential risks indicated appears irresponsible.

One of the difficulties in communicating health risks attributable to fish consumption is balancing the very real health benefits of eating fish with theoretical or uncertain risks. Salmon are often regarded as being a relatively “clean” fish with a high level of omega-3 fatty acids that reduce the risk of heart disease and with other health benefits. For this reason, people are often advised to eat salmon and other low-contaminant fish, as opposed to fish that typically have high levels of contaminants. DOH agrees that there is a risk of eating an unlimited amount of salmon, or any other fish in the world, for that matter. DOH considers salmon the

preferred fish to eat from the LDW because of their relatively low level of contaminants and the high level of omega-3 fatty acids. Consumption limits have not been set for LDW salmon because of the health benefits.

11. A discussion of cancer risk from consuming salmon should be presented, especially in light of recent studies on the Columbia River that determined that salmon consumption there poses an unacceptable cancer risk to tribal fishers. A comparison of fish tissue and sediment concentrations between the Columbia and Duwamish Rivers should be provided.

EPA's Columbia River Basin Fish Contaminant Survey reported individual cancer risks of 1×10^{-3} associated with high-end consumers of coho, chinook, steelhead, eulachon, and Pacific lamprey. The majority of these cancer risks were attributable to arsenic and dioxin TEQ (includes dioxin-like PCB congeners).

The cancer risk associated with a high-end consumer of all anadromous fish from the LDW is 9×10^{-4} (Table C5). The majority of this risk is attributable to cPAHs and arsenic. It is important to reemphasize that cPAHs were not detected in any finfish, and the amount of inorganic arsenic assumed to be in finfish is uncertain. A key difference between the data that were available for the Columbia River Basin Fish Contaminant Survey and the data used in the PHA was that there was no dioxin TEQ data available in the LDW fish.

Aroclor levels in the few Columbia River Basin salmon do appear to be lower than in LDW salmon; however, there may be explanations for these differences because of the geographic differences of the two waterways. For instance, many of the fish in the Columbia were sampled from fresh water locations a great distance from salt water, whereas LDW salmon were sampled in a marine environment or in brackish water. Returning salmon stop feeding as they swim up fresh water streams, relying solely on their fat reserves. In the process of mobilizing their fat, they release PCBs into their blood stream, where it is either repartitioned to remaining fat and other organs or excreted. A comparison between these two different populations of coho, therefore, is not appropriate.

12. The PHA concludes that there is no apparent public health hazard associated with children's contact with contaminated sediment at public access locations. The RI identified a potential sediment data gap near public access points.

The PHA acknowledges a paucity of intertidal sediment samples near public access areas. However, it was assumed that the 1,200 samples taken from the LDW were taken in areas thought to be contaminated, thus being biased toward finding areas with the most contamination. While this may not be true in all cases, it was assumed that the sediment was adequately characterized with respect to direct contact pathway. DOH understands that more sediment sampling may occur at public access areas, and DOH will reevaluate the data once they are available.

13. Why does the PHA consider that all the seafood people consumers come from the LDW?

In terms of assessing hazards associated with a site, DOH chose to evaluate a worst-case scenario. The results of the evaluation revealed that a subsistence level consumption of resident fish from the LDW could result in adverse health effects. Accordingly, DOH has issued a fish advisory for resident fish in the

Duwamish River (See Recommendations on page 58). Furthermore, consumers who eat a lot of fish as a routine part of their diet should avoid eating resident fish from the LDW because all fish have some level of contamination.

14. What consideration was given to lead exposure at beaches?

Lead was not considered as a contaminant of concern in sediment because the 95th percentile lead concentration of all sediment samples was below the comparison value (see table F5). However, 32 sediment samples contained lead above comparison values, and nearly half those samples were taken from a single area. None of the samples with elevated lead levels were located at or near public access areas. EPA and LDWG plan to further characterize sediment contaminant levels near public access points, at which time DOH will be available to reevaluate lead and other contaminant exposure at public beaches.

15. EPA's revised guidelines for assessing cancer risks to children should be used to reassess cancer risks for children in the Public Health Assessment for the Lower Duwamish River.

See the child health considerations section on page 48.